ABSTRACT

DOTGER, SHARON RUTH. Cognitive and Developmental Components of Understanding the Nature of Science. (Under the direction of M. Gail Jones).

The purpose of this study is to determine the degree to which years of education, college major, or reflective judgment stage influences individual's understandings of the nature of science. Using a cross-sectional design influenced by the literature describing the development of reflective judgment and nature of science understandings, this study encompasses the viewpoints of 323 individuals from ninth grade through graduate study. This research involves the careful selection of instruments for assessing these two complex constructs, and the processes used to select and rate participants responses is described in detail. Multinomial ordinal regression was used to determine the significance of educational level, major, and reflective judgment on nature of science views. Results indicate that high school students as a whole are least likely to respond appropriately to questions about the nature of science. However, the performance of college students is inconsistent with predictions, college freshmen more often select the desired response than college seniors or graduate students. Additionally, college major has no significant impact on nature of science understandings. Reflective judgment, a term that describes cognitive developmental model of advanced thinking skills, is found to have the most significant correlations with nature of science views. Reflective thinkers are more likely to select the desired nature of science response than quasi-reflective and pre-reflective thinkers for six of the ten questions. Discussion of results is followed by implications for science teaching and learning in K-12 classrooms.

COGNITIVE AND DEVELOPMENTAL COMPONENTS OF UNDERSTANDING THE NATURE OF SCIENCE

by

SHARON DOTGER

A dissertation submitted to the Graduate Faculty of
North Carolina State University
in partial fulfillment of the
requirements for the Degree of
Doctor of Philosophy

SCIENCE EDUCATION

Raleigh

2006

APPROVED BY:

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Chair of Advisory Committee	
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DEDICATION

To my great-grandmother, Mary Gazda Kaszyca, whose unique approaches to life and education have inspired me throughout the years.

To my grandparents, Kenneth & JoAnne Vadasy and Swann & Ruth Crutchfield, thank you for always demonstrating your love and support.

To my brother, Chris Crutchfield, thank you for always being there to listen.

To my sister, Cathy Crutchfield, your passion always helps propel me forward.

To my parents, Steve & Cheryl Crutchfield, you've always been behind me. I'd need another dissertation to describe all that you mean to me. On a side note, as far as being a student, I'm done.

To the girls, Kerri Barnhart, Sharon Cobb, Amanda Johnson, Bethany Smith, and Leslie Snow. I never knew that friendship could be like this.

To the Mahr family, you help Ben and I keep it all in perspective.

To Richard, thank you for supporting us and being our long-time mentor. You are family.

To Ben, you are my true companion. Without you, none of this would have been possible.

BIOGRAPHY

Sharon Ruth Crutchfield was born in Huntsville, Alabama in August of 1976. Her early years were punctuated by five moves that finally settled the family in Concord, North Carolina in the fall of 1990. After high school, she earned a Biology degree in 1998 from the University of North Carolina, Chapel Hill and graduated with the honor of Morehead Scholar.

Sharon immediately began her teaching career in Concord, attending courses for teaching certification at night at the University of North Carolina, Charlotte. In December of 1999, she married Benjamin Dotger. In 2001, she began her studies for her Master's degree at Montana State University. One week after completing the Master's and after five years of public school teaching, she and Ben moved to Raleigh to attend North Carolina State University.

Together, she and Ben have built a house, taught, earned graduate degrees, enjoyed the company of their dog, Maggie, and are eagerly expecting the birth of their first child.

ACKNOWLEDEMENTS

No dissertation is solely the work of one individual. There are many who have supported my efforts to complete this research and I am grateful to each of them.

Dr. M. Gail Jones, my advisor and chairperson, was supportive of this research from the first car ride in which we talked about it. Her energy and fervor for the research process have been instrumental in moving this project from an idea to a reality.

My committee members, Dr. Glenda Carter, Dr. Len Annetta, and Dr. Dave DeMaster offered much advice and guidance throughout. Their careful reading, listening, and commentary have been much appreciated.

Dr. Alan Reiman, a teacher and mentor, helped me refine my conceptions of reflective judgment and has always made himself available for questions. I am consistently impressed by his commitment to living and demonstrating the principles he teaches others.

Dr. Bonnie Fusarelli encouraged me through the process of graduate school. Her mentorship, on both a professional and personal level, has given me the confidence to continue the journey into the academy.

Ben Dotger, my husband and colleague, who defends his dissertation the same day as I do, has listened to multiple ideas, read drafts of my work, soothed and supported me through the bumps, and celebrated the victories. I am continually amazed by him and am so very glad to have him as a partner.

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INTRODUCTION

This dissertation is organized into three articles, each of which describes a component of the overall dissertation study. The first article describes the current research on the nature of science including a discussion of how nature of science is defined from multiple perspectives. Furthermore, the first article analyzes prior research on the assessment of students' understandings of the nature of science. The second article discusses the use of the Views-on-Science-Technology-Society assessment to measure 323 students' understandings of nature of science. The third article describes a student of 323 individuals' concepts of nature of science as well as these individuals' levels of reflective judgment. A discussion of nature of science in relationship to cognitive development is included. In the paragraphs that follow, each article is identified by its title and a brief abstract.

THE INFLUENCE OF THE NATURE OF SCIENCE ON SCIENCE EDUCATION

This study analyzed prior research on the articulation, design, and assessment of nature of science objectives for K-12 science education. It documents the emerging consensus regarding the definition of nature of science and the importance of addressing this topic through explicit and reflective practice. Furthermore, this review describes the difficulty in developing understandings of the nature of science for both students and teachers and discusses the myriad of approaches that have been used with these groups. The success of past studies in measuring nature of science is discussed and areas for future work are described.

USING THE VIEWS-ON-SCIENCE-TECHNOLOGY-SOCIETY INSTRUMENT TO COMPARE NATURE OF SCIENCE VIEWS BETWEEN GROUPS

This study examined the the Views-on-Science-Technology-Society (VOSTS) (Ryan & Aikenhead, 1992) assessment as a tool to measure students knowledge nature of science. Ninth grade through graduate school students' views were measured using a subset of questions from the VOSTS. Statistical comparisons of students' views were made across the educational levels represented. Comparisons were made among college students according to their majors. The VOSTS questions and the subsequent analysis of ratings of answer choices are presented. Analysis was conducted using multinomial ordinal regression, resulting in a Wald chi-square test statistic. Each question was analyzed separately. Results indicated that high school students responded to VOSTS questions significantly differently from college students for five of the eight questions. College major had minimal effect on the responses of college students.

EXPLORING DIFFERENCES IN VIEWS OF NATURE OF SCIENCE AS A FUNCTION OF THE DEVELOPMENT OF REFLECTIVE THINKING

The science education community has worked for years to develop nature of science understandings among students and teachers. Theses efforts have yielded mixed results. Reflective judgment, which describes an individual's cognitive processes as he/she makes decisions about complex, ill-structured problems, is related to the types of thinking individuals need to engage in when thinking about the nature of science. This study assessed the reflective thinking skills and the nature of science understandings of 323 individuals representing a continuum of education and reflective judgment skill. Results indicated that for six of the ten nature of science questions, reflective thinkers had a more sophisticated understanding of nature of science.

THE INFLUENCE OF THE NATURE OF SCIENCE ON SCIENCE EDUCATION: A REVIEW OF THE LITERATURE

Citizens in Western societies are confronted daily with the need to understand science-related social issues like genetically modified foods, stem cell research, products including nanotechnology, and vaccinations. The complexity of these issues raises questions about how to best prepare citizens to make decisions related to science and technology in their lives. What should be the goals for the science taught in schools? Is the goal to prepare future scientists or, alternatively, to prepare laypeople to become consumers of science? Are these two ideas mutually exclusive, or can school science serve them simultaneously? Is an understanding of science, its process, and its products necessary in order to sustain democracy? These issues are at the heart of the debate to reform science education. As demonstrated by DeBoer (1996), scientists often push for the preparation of future scientists, while K-12 teachers, by necessity, focus on broadly preparing students who will go out into a variety of occupations. Can we educate all citizens about the nature of scientific inquiry, including the fundamental premises that drive scientific research, while also providing students with a solid foundation of essential scientific concepts and processes?

Economic, utilitarian, democratic, social and cultural justifications have been used to support the teaching of science. These justifications are significant because very few students become scientists; most students will not study science beyond their years of compulsory schooling (Millar, 1996). However, there was a time in which the primary purpose of science teaching was thought to be helping students prepare for college science courses or careers in science and technology (Klopfer, 1969). For the most part, K-12 educational objectives in science are still aligned with the goal of preparing future scientists (Osborne, et al., 2003). In many countries such as the United States, a single curriculum tries to address the needs of the future scientists as well as the future consumers of science. One perspective is that science curricula ought to be based on ideas that are most likely to enter the public discourse or influence personal actions (Millar, 1996) and these ideas should be evaluated based on their utility for most students (Osborne, et al., 2003). Thus, this perspective concludes that the aim of public schooling in science is to produce more effective citizens, rather than future scientists (Smith & Scharmann, 1999).

Questions regarding the purpose of science teaching have driven science educators to include the nature of science (NOS) as a major component of standards, goals, and curricula in an effort to serve all students. The potential success of these efforts has been questioned, with resolution of the challenge recommended by including the entire educational community, rather than only science educators in the construction of curriculum to address NOS (Hipkins, et al., 2005). Although NOS has taken on a more prominent role in standards and curricula, it has required an examination of the definition of science as a unique way of knowing. In addition, the inclusion of NOS objectives has called for an evaluation of the effectiveness of NOS instruction in changing students' views of science. This literature review will evaluate the historical roots of NOS, the arguments for including NOS as a major component of the curriculum, the attempts to measure students' and teachers' conceptions of NOS and the results of these studies. Additionally, this review will evaluate the difficulties of fully achieving the outcomes for NOS understandings, as well as suggestions for developing NOS understandings in K-12 teachers and students.

Method

This literature review evaluates the progression of the effort to include NOS in K-12 instruction and pre-service teacher preparation since the late 1960's. The literature describes methods for evaluating individuals' understandings of NOS, the results of these evaluations with students, teachers, and scientists, as well as suggestions for the inclusion of NOS in curriculum and instruction. These articles were collected from ERIC, the Web of Science, and PsychInfo databases using search terms like *nature of science*, *scientific literacy*, *epistemology of science in education* and *philosophy of science*. Additional articles were found by scanning the reference list of recently published articles about NOS.

These articles were then grouped based on the type of participant included in the study, whether student, teacher, or scientist. Some articles report the development or evaluation of an instrument and others include participants' perceptions of NOS as reflected in the instruments. Many articles discuss the reasons NOS should be addressed for science students in K-12 and undergraduate education. Historically, it has been difficult to articulate what is meant by NOS and to write educational objectives for NOS instruction. Articles that address this issue are discussed. Most articles include one or more of above the tenets and are organized accordingly.

Historical Challenges for Defining NOS

Early justifications for the inclusion of NOS in K-12 curricula and in teacher education resulted in a wide variety of definitions for NOS. In an attempt to create an inclusive definition, NOS was described as the values and assumptions of scientific knowledge, part of an individual's scientific literacy (Lederman, 1986).

Over time, tenets were developed to describe NOS in a more definitive way. The specification of the attributes of NOS was driven by a need to delineate NOS objectives for K-16 education that were separate from the philosophy of science and a need to measure growth within teachers' and students' views of NOS in the K-16 educational setting. A common set of tenets has emerged that is widely used in science education research. These tenets are:

(1) scientific knowledge is:
    i. tentative
    ii. empirical
    iii. theory-laden
    iv. partly the product of human inference, imagination, and creativity
    v. socially and culturally embedded
(2) there is a distiction between observation and inference
(3) there is not a universal recipelike method for doing science
(4) understanding the functions of and the relationships between scientific theories and laws (Lederman, et al., 2002).

These essential tenets form the foundation for a larger dialogue about the nature of science, a dialogue that is not trivial or inconsequential. For scientists seeking funding from governmental agencies, to those who communicate findings to the policy makers who then design legislation for scientific developments, this issue of defining and educating others about what science is, how science is conducted and how to make sense of scientific findings is of critical importance. The aspects of science identified by the tenets are described in detail in the sections that follow.

Historically and by definition, scientific knowledge can change and can never be certain. There are numerous examples from the history of science of the tentative nature of scientific knowledge. Changes in knowledge may occur in light of new evidence, generated either by new technologies (like microscopes or telescopes), changes in culture, or the goals of research programs. Changes may also be due to the emergence of new theory accompanied by a reinterpretation of old evidence. The lack of certainty is not only a product of interpretation or the quality of technology; it is also a fundamental component of scientific reasoning. Since hypotheses can never be proven, only refuted, there exists a possibility that theories and laws might one day be changed because they do not adequately explain all observed phenomena (Lederman, 1998; Lederman, et al., 2002; Khifse & Abd-El-Khalick, 2002; McComas, 2004). These tentative characteristics of science emerge from the complex interaction between scientists' beliefs, methods of inquiry, use of theories, as well as the human limitations of scientists themselves (Botton & Brown, 1998).

The empirical aspect of NOS describes the effort of science to interpret nature (Carey & Stauss, 1968) by making observations of it (Lederman, et al., 2002). It is important to keep in mind that not all scientific observations are made through the five senses alone. Often, scientists use tools and instruments to gather data and the assumptions scientists make about the workings of these instruments impact the resulting observations. These scientific observations, alone, do not generate scientific knowledge. Scientists use these observations, along with their imagination and creativity, to propose explanations, hypotheses, and theories (Akerson, et al., 2000; Lederman, 1998; Lederman, et al., 2002).

Theories influence scientists' work, along with their own belief structures, expectations, prior knowledge and experiences, and previous training. Each of these factors can influence the way scientists conduct their investigations, predisposing them to recording some observations while ignoring others, thus altering the way interpretations are made. The theory-laddenness of science refers to these effects of theories on investigations, observations, and the generation of new theories (Brickhouse, 1991; Lederman, 1998; Lederman, et al., 2002).

The description of science's social and cultural embeddedness means that science is affected by the political structure of the society in which it is conducted. It is also impacted by the socioeconomic factors and power relationships of the larger society (Lederman, et al., 2002; McComas, 2004). The cultural conditions a scientist works within "shape what topics are pursued, what questions are asked, what observations are noticed, how evidence is interpreted, and theoretical virtues are preferred" (Allchin, 2004, p. 938). This was seen in the church's influence on the work of Galileo, when under their influence he retracted some of his explanations for the movement of the planets and stars (DeWitt, 2001). Philosophy and religion influence scientists, and thus impact the type of science that they conduct (Abd-El-Khalick, et al., 1998; Lederman, 1998).

Additional aspects of NOS include understanding the differences in observations and inferences. Observations are made directly from nature, either with the senses alone or aided by tools, whereas inferences cannot be measured directly, but are used to explain observations. For example, when gravity is used to explain why an object falls, the falling object is the observation and gravity is the inference (Akerson, et al., 2000; Chiapetta & Kobala, 2004; Lederman, 1998; Lederman, et al., 2002;).

There is a growing interest in having students understand there is not a single scientific method that all scientists follow. Having a step-wise methodology for conducting science is not an accurate depiction of how science actually is conducted (Allchin, 2004). Instead, scientists use a variety methodologies that differ within and across the domains of science. The danger in thinking that scientists only conduct their investigations one way might lead one to think that if a series of steps were followed, a correct answer would always be found (Abd-El-Khalick & Boujaoude, 1997; Lederman, 1998; Lederman, et al., 2002).

While these detailed descriptions of the tenets are helpful in understanding NOS, they are not exhaustive. One of the difficulties in defining NOS is the absence of a single, agreed upon philosophical stance that supports NOS for K-12 science education. Agreement or disagreement with tenets is strongly related to the philosophical position of the evaluator (Alters, 1997). Given the multidimensional nature of the scientific enterprise, the problem of singly defining NOS is understandable (Lederman, et al., 2002; Moss, et al., 2001). Nonetheless, there is sufficient practical agreement about the components of NOS for the purposes of K-12 instruction (McComas, Almazroa, & Clough, 1998; Smith, et al., 1997). Although the existence of standards (AAAS, 1993; NRC 1996) would seem to make this debate obsolete, the problem continues because these documents are typically the result of committee compromises, rather than a representation of agreements reached among science educators (Osborne, et al., 2003). As noted by Good & Shamansky (2001), these standards documents present statements that support multiple philosophical perspectives.

In an effort to find a common definition for NOS, Osborne, et al., (2003) conducted a Delphi-study with 25 science educators, scientists, historians, philosophers, and sociologists of science. Through three rounds of evaluation, rating, and editing, nine themes emerged as having the greatest consensus and stability among the participants. These were: Scientific Method and Critical Testing, Creativity, Historical Development of Scientific Knowledge, Science and Questioning, Diversity of Scientific Thinking, Analysis and Interpretation of Data, Science and Certainty, Hypothesis and Prediction, and Cooperation and Collaboration in the Development of Scientific Knowledge. These themes are all related to one another, indicating that while the experts may agree that these should be taught explicitly, they could not be effectively taught in isolation from one another (Osborne, et al., 2003).

This Delphi study provided support for the claim that there was a consensus regarding which aspects of NOS should be taught to K-12 students. As noted by Osborne, et al. (2003), the emerging themes in the Delphi study matched common principles previously identified by McComas & Olson (1998) in a study of international standards documents. Additionally, qualitative interviews with experienced scientists from multiple disciplines further revealed that scientists are generally able to consistently describe the characteristics of NOS (Schwartz & Lederman, 2005). The differences in the language used to describe the characteristics of NOS make it difficult to accurately compare the tenets used in Lederman's (2002) work to those identified by Osborne (2003). However, there are similarities. Both value the teaching of scientific processes, while stressing that a single scientific approach does not exist. Both are interested in teaching students the role of creativity in science, as well as science being grounded in the collection and interpretation of data. Each addresses the role of change in the development and interpretation of scientific facts. Across studies, a common view of the nature of science for science education has emerged.

Including NOS in the K-12 Science Curriculum

Educators have argued for the inclusion of NOS in the science curriculum as a way to promote students' science literacy for 45 years (Behnke, 1961; Klopfer, 1969; Meichtry, 1992, 1993). NOS goals have been incorporated into the *National Science Education Standards* (NRC, 1996) and the *Benchmarks for Science Literacy* (AAAS, 1993). These American standards documents addressed NOS in much the same way that state and international documents have included NOS as goals for science education (McComas &

Olson, 1998). However, even with this goal to teach students about NOS, teachers continue to adhere to teaching science as a body of facts (McComas, Almazroa, & Clough, 1998).

Arguments have been made that an ideally constructed science education curriculum would help students understand more than science content; it would help them understand how science is related to larger cultures (Matthews, 2001). Clough (2000) maintains that science teaching is effective when it reveals to students the fundamental assumptions operative in the building of scientific knowledge so that students may cross into the scientific culture whenever they feel the need. Science is becoming an ever-increasing part of the daily lives of all people and an understanding of NOS is essential for engaging more fully with the issues science presents (Osborne, et al., 2003). Consequently, there is an emerging consensus that NOS is "…an essential and central element to the school science curriculum" (Bartholomew, Osborne, & Ratcliffe, 2004, p. 655).

A frequently repeated justification for teaching NOS to students is that NOS understanding is strongly related to the development of responsible decision-making and positive citizenship (Meichtry, 1992; Smith & Scharmann, 1999). These understandings of NOS have the potential to help students become intelligent consumers of scientific knowledge and to make thoughtful, informed decisions. Decision-making and citizenship goals are often associated with a science curriculum that is focused on the relationships among science, technology, and society (STS). In fact, NOS is "implicitly associated" with STS in modern concepts of science education (Sadler, Chambers, & Zeidler, 2002, p. 2). The implicit argument is that in order for students to make better decisions about STS issues, they need an awareness of ethical problems and political challenges. Teaching NOS helps students understand the ways scientists' work is impacted by their morals and ethics (Zeidler, et al., 2002).

Arguments for the inclusion of NOS objectives in the science curriculum began as early as 1961, when Behnke developed a questionnaire to survey high school teachers and scientists about public beliefs about science. This population was chosen for the survey because of the researcher's belief that the opinions of science teachers about science and its influence on American life impacted the quality of their teaching. The teachers were selected from the National Science Teachers Association and the scientists were chosen from the American Association for the Advancement of Science (Behnke, 1961). Over half of the teachers and 20 percent of scientists in this study felt that scientific results were not tentative. Additionally, half the teachers felt the substantive content of science was fixed and unchangeable; although there was no identification of what teachers thought constituted substantive content. Half of the teachers and a majority of scientists felt that a high level of intelligence were necessary in order to become a scientist. Both groups were almost in complete agreement that scientists ought to help the public better understand their work and scientists should be involved in the development of public policy. Notably, there was greater homogeneity in the teachers' responses across the disciplines than there was among the scientists (Behnke, 1961).

Results of exploratory studies like Behnke's (1961) helped to spur discussion about what ought to be included in the science curriculum with regard to NOS. Calls for a greater inclusion of NOS in the curriculum continued, corresponding with a view in the science education community that students had not demonstrated sufficient concepts of NOS (Kimball, 1967-1968). Researchers at the time maintained that science needed to be taught as both science process and method, rather than only as content (Rutherford, 1964; Welch & Pella, 1967-1968). However, even as the call for inclusion of NOS objectives in instruction increased, there was a concurrent lack of NOS instruction showing up in classroom practice. Calls for including NOS in the curriculum were initially tied to teaching science using an inquiry process (Abd-El-Khalick, et al., 2004; Rutherford, 1964), as this helped to link the knowledge of science with the methods that produced that knowledge. The argument was made that teachers should be taught more about how inquiry was really conducted in the laboratory so that they could represent science more authentically to their students (Rutherford, 1964).

During the 1960's, science curricula were influenced by learning theories and the philosophy of science (Carey & Stauss, 1968). At that time, the importance of laboratory work in students' learning was emerging in science education along with a commitment to teaching through inquiry methods. NOS was seen as an integral part of this effort because it described how science progressed (Carey & Stauss, 1968). Other researchers thought addressing science literacy in the curriculum would improve science teaching (Manual, 1981) and would help dispel large-scale misconceptions (Rubba, Horner, & Smith, 1981). However, early efforts to include more philosophy of science in the curriculum were not successful (Duschl, 1985; Ivany, 1969). One reason for this failure was that new curricular development occurred independently of changes in teacher education, and most of the curriculum development teams did not include a specialist in the history and philosophy of science (Abimbola, 1983; Duschl, 1985;).

Educating Teachers about Nature of Science

It has been argued that teachers ought to understand NOS so they can convey this understanding to their students (Andersen, Harty & Samuel, 1986; Bentley & Garrison, 1991). It is assumed that teachers' views of NOS impact their classroom behavior and their pedagogy (Herron, 1969; Robinson, 1969). Haukoos & Penick (1983) maintained that teachers who establish a classroom climate committed to discovery are more likely to develop understandings of the processes of science with their students. This view of science as a process of construction and reconstruction may further translate into instruction that helps students build and rebuild meaning from their experiences (McComas, Almazoa, & Clough, 1998).

NOS advocates argue that when teachers understand NOS, they can better represent the differences between theories and laws, the roles of observation and experimention, and the differences between school science and laboratory science (Manual, 1981). The argument suggests that teachers can more accurately represent scientific theories to their students (Farber, 2003). As elementary teachers are exposed to more science instruction, they are better prepared to scaffold students' learning during science lessons (Haigh, 2005). Loving (1991) noted that as changes in curricular emphasis occur, teachers need a deeper conceptual understanding of what science is and what makes it unique from other disciplines. Teachers should also be given the opportunity to learn how the many disciplines of science are similar to and different from one another and what theories and methods unite these domains (Loving, 1991).

Preservice Teacher Education

Preservice teachers' views of NOS lie on a continuum between traditional and contemporary (Palmquist & Finley, 1997). Researchers cite teachers' responsibility to disseminate knowledge that appears fixed in textbooks, suggesting that it is not surprising that teachers do not have sophisticated conceptions of NOS (Behnke, 1961) and that school cultures that emphasize control over creativity are likely to influence teachers' philosophies of science (Brickhouse, 1991). Historically, it was assumed that teachers' conceptions of NOS were related to their students' conceptions and were likely to translate into classroom practice (Abd-El-Khalick, Bell, & Lederman, 1998; Bentley & Garrison, 1991) as their selection of content portrays NOS in a certain way (Palmquist & Finley, 1997). Thus, if teachers have a poor understanding of NOS, their students will as well (Lederman, 1986).

Measuring NOS Understandings

A strong effort to measure individuals' understandings of NOS has been associated with the evolving call for NOS instruction. Multiple instruments (summarized in Table 1) have been developed to assess NOS understandings. Many include forced choice Likert-type scales designed to measure attitudes, some are more similar to a multiple choice test intended to assess views, and others involve answering open-ended questions. NOS understandings have also been assessed through the use of interviews. No single method seems to adequately capture an individual's view of NOS, and some researchers have argued that these views are best assessed through a combination of qualitative and quantitative methodologies (Smith, et al., 1997). The multiple inventories, as well as the procedures used to create them, are summarized in the table 1.

Table 1: *Comparison of Instruments used to assess NOS*

Author	Year	Instrument	Development	Intended Audience	Components of NOS addressed
Welch & Pella	1967-1968	Science Process Inventory (SPI)	16 philosophy of science books	K-12 students	Activities, products, assumptions & ethics of science
Kimball	1967-1968	Nature of Science Scale (NOSS)	Statements generated from literature and reviewed by science teachers, supervisors, educators, & professors	Undergraduates	Tentativeness, subjectiveness, processes and products of science
Welch &Walberg	1967-1968	Test on Understanding Science (TOUS)	Philosophy of science literature	K-12 Students Undergraduates	Tentativeness, acitivities of science
Rubba & Anderson	1977	Nature of Scientific Knowledge Scale (NSKS)	Philosophy of science literature	K-12 Students, teachers, and college students	Tentativeness, activities of science
Cotham & Smith	1981	Conceptions of Scientific Theories Test (COST)	Philosophy of science literature	Undergraduates	Tentative aspects of science
Aikenhead & Ryan	1992	Views on Science-Technolgoy-Society (VOSTS)	Creating prompts from student interviews, and retesting prompts with other students	K-12 Students	Characteristics of scientists, domain & epistemology of science, use of science in decision making, interaction of STS
Lederman & O'Malley Abd-El-Khalick, et al. Lederman, et al.	1990 1998 2002	Views on Nature of Science (VNOS), Forms A, B, & C	Statements generated from literature, reviewed by experts, and compared to student interviews	K-12 Students, preservice teachers, & inservice teachers	Theory-ladenness, empirical NOS, tentativeness, influence of imagination, creativity, and inference, social & cultural embeddedness

One of the earliest assessments was the *Science Process Inventory* (SPI) developed by Welch & Pella (1967-1968), which contains 150 statements about the activities, products, assumptions, and ethics of science. These statements emerged from an examination of different texts that described the scientific process. If the concept was addressed in three out of the sixteen books referenced, it was included in the inventory. Fourteen research scientists reviewed the statements taken from the literature to address the content validity of the assessment (Welch & Pella, 1967-1968).

Working to get a sense for how science teachers' views of NOS were different from those of scientists, Kimball (1967-1968) developed the Nature of Science Scale (NOSS). The instrument was also designed to evaluate the way scientists', teachers', and philosophers' views may change following their undergraduate education. The instrument was developed with an initial group of 200 statements which were analyzed by science teachers, science supervisors from schools, science professors, and professors of science education. After multiple stages of revision, the final assessment included 31 items that had a split-half reliability of 0.72 and effectively discriminated between experts and novices (Kimball, 1967-1968).

The *Test on Understanding Science* (TOUS), developed by Welch & Walberg 1967-1968), contains 60 questions with four multiple-choice responses per question. The reliability of the total score on the instrument was shown to be 0.76 (Meichtry, 1993). Rubba (1977) developed the *Nature of Scientific Knowledge Scale* (NSKS) to assess students', teachers', and undergraduates' views of NOS. The scale includes 48-items with Likert-scale answer choices with a reliability of 0.84 (Meichtry, 1993).

In an attempt to improve on previous instruments, the *Conceptions of Scientific Theories Test* (COST) was developed by Cotham & Smith (1981) with the intention of offering answer choices that were more sensitive to multiple positions regarding the philosophy of science and allowed for the expression of alternative conceptions. Additionally, the authors of the instrument reportedly focused on those aspects of the philosophy of science that were most relevant to science teachers. This instrument assessed the tentative aspects of science and features specific examples, such as Bohr's model of the atom and Darwin's theory of evolution, in the questions. The primary source for the questions was the philosophy of science literature. The original 80 items were tested with 56 college physical science students and 40 questions were selected after a Pearson correlation was calculated between pairs of items. In order to assess the construct validity, the questions were given to elementary education majors, philosophy majors, and chemistry majors to see if the questions could discriminate between these groups. The analysis of the responses revealed that elementary education majors were more likely than philosophy majors to adhere to conclusive conceptions of theory testing, inductive conceptions of the generation of theories, and objective conceptions of theory choice. Elementary education majors were not significantly different from chemistry majors in their views, as measured by the COST (Cotham & Smith, 1981).

Prior to the creation of the Views on Science-Technology-Society (VOSTS) instrument developed by Aikenhead and Ryan (1992), written assessments of NOS understandings assumed that the assessment author and the student interpreted the items in the same way (Aikenhead, 1988). Due to its unique method of development, the VOSTS instrument was a departure from these problems. The development of items for the VOSTS involved five steps which included (1) the identification of content from science standards and research in science education, writing prompts, and asking high school students to respond to the prompts; (2) summarizing and analyzing student answers; (3) rewriting these summaries as answer choices to the prompts, and retesting with another group of students; (4) and finally testing with a large sample of students and eliminating answer choices that were seldom chosen (Aikenhead & Ryan, 1992). The authors of the instrument reported that this naturalistic approach valued and preserved the students' perspectives, rather than those of philosophers and science educators, and as such should be considered a valid measure of student points of view. The VOSTS, though grounded in student views, is limited in that it does not result in a total score. The multitude of answer choices allows many views to be represented, but limits statistical analysis of responses.

Other researchers have sought to establish the validity of VOSTS questions in a more statistically rigorous, less subjective manner (Botton & Brown, 1998). To do this, questions focusing on the definition and the epistemology of science were taken from the VOSTS and given to university students. Each of the students held an undergraduate degree in science. In this study, a test, re-test method was employed in an effort to evaluate the validity of the questions. Cluster analysis, cross-tabulation, and chi-square statistics were used to test for item independence, homogeneity of student groups, and consistency. The data analysis indicated VOSTS reliability and the items included in this study that refer to the definition and epistemology of science are reasonable assessments for educational purposes (Botton & Brown, 1998).

The VOSTS assessment was followed by the development of the Views on the Nature of Science (VNOS) by Lederman & O'Malley (1990). The VNOS was designed to address validity concerns about the previous paper and pencil assessments and how students interpreted the questions. The VNOS, unlike previous assessments, used interviews in addition to open-ended written responses to evaluate student understandings. The first version of the VNOS questionnaire contained seven questions. Analysis of the semi-structured interviews with the students revealed that the researchers' interpretations of the meaning of students' written responses were inaccurate in three of the seven cases. This finding led to a revision of the original VNOS and provided additional evidence for questioning the validity of earlier assessments (Lederman & O'Malley, 1990).

Following the first revision of the VNOS (VNOS-A), a second form was developed (VNOS-B) to assess the views held by preservice teachers. Like form A, form B utilized written items followed by individual interviews. As before, participants were asked to clarify their written responses and explain their understandings of key terms in the questions. These interviews were also designed to clarify obscure answers and apparent conflicts in participants' views. After repeated testing with the instrument, researchers found that sufficient understandings of students' and teachers' views could be obtained with interviews from 15%-20% of the participants (Abd-El-Khalick, et al., 1998). Further modifications were made to the VNOS. Five of the items were adapted and five more were added to the ones included in form B. Thus, VNOS-C produced similar findings to the earlier versions (Lederman, et al., 2002).

In summary, for nearly 50 years researchers have worked to assess changes in students' and teachers' conceptions of the nature of scientific inquiry. Paper and pencil assessments have suffered from a lack of consistent interpretations by students, as well as lack of consistency in the philosophical basis underlying the questions. Furthermore, assessments with interviews are difficult and very expensive to administer, making it difficult for classroom teachers to evaluate the views of their students and for researchers to assess NOS views in studies with large sample sizes. Future work in NOS may result in an assessment tool that is scorable, reliable, and employable with a large number of subjects.

Conceptions of NOS

Studies across groups have shown that teachers, students, scientists and philosophers of science differ in their conceptions of NOS (Abd-El-Khalick, Bell, & Lederman, 1998; Palmquist & Finely, 1997; Scharmann & Harris, 1992; Schmidt, 1967). Regardless of the instrument used, multiple studies have found that teachers do not have understandings of NOS that are consistent with those articulated by the stated goals of science education (Akerson, Abd-El-Khalick, & Lederman, 2000). Furthermore, efforts within science education have not been broadly successful in improving students' and teachers' NOS conceptions. Table 2 summarizes teachers', students', and scientists' conceptions of NOS. These studies have been conducted in a wide variety of contexts, with multiple assessments evaluating participants' views.

Table 2: Teachers, Students, & Scientists Conceptions of NOS

Author	Year	Participants	Intervention	Assessment	Design
Welch & Walberg	1967-1968	Teachers	Summer Institute Focus: Physics	TSTP TOUS SPI	Pre and post test
Welch & Pella	1967-1968	Teachers Students, grades 10 & 12 Scientists	None	SPI Henmon-Nelson Test of Mental Ability Iowa Test of Educational Development	Cross-section Comparative
Kimball	1967-1968	Undergraduates, various majors	None	NOSS	Cross-section Comparative
Carey & Stauss	1968	Pre-service teachers	Coursework	WISP	Pre and post test
Lavach	1969	Teachers	Course Focus: History of Science	TOUS	Pre and post test
MackKay	1971	Students, grades 7 – 10	Year long school science courses	TOUS	Pre and post test
Billeh & Hassan	1975	Teachers	Summer Institute Focus: Pedagogy	Researcher Developed Questionnaire	Pre and post test
Bady	1979	Students, grades 9 – 12	None	Student evaluation of hypotheses developed by the researcher	Exploratory
Rubba, et al.	1981	Students, grades 6 - 8	Science Fair	Researcher Designed Questionniare	Exploratory

Table 2: Teachers, Students, & Scientists Conceptions of NOS, continued

Author	Year	Participants	Intervention	Assessment	Design
Zeidler & Lederman	1985	Teachers Students, grade 10	High school biology course	NSKS Classroom Observations	Pre and post test
Lederman	**1986**	Teachers Students, grade 10	High school biology course	NSKS	Pre and post test
Zeidler & Lederman	1989	Teachers Students, grades 9 – 12	Biology Course	NSKS Classroom Observations	Pre and post test
Brickhouse	1991	Pre-service Teachers	Preservice coursework	Interviews, observations, textbook evaluation	Qualitative participant observation
Ryan & Aikenhead	1992	Students, grades 11 & 12	None	VOSTS	Exploratory
Scharmann & Harris	1992	Teachers	Summer Instiitute	NOSS	Pre and post test
Meichtry	1992	Students, grades 6 –9	Traditional v. Alternative textbooks	NSKS Classroom observations Interviews	Pre and post test
Griffiths & Barman	1995	International Students, grades 9 – 12	None	Research Developed Questionnaire	Exploratory
Rubba, et al.	1996	Undergraduates enrolled in physis & STS courses	Physics v. STS course	VOSTS	Pre and post test
Leach, et al	1997	Students, age 9 – 16	None	Card-sort	Exploratory

Table 2: Teachers, Students, & Scientists Conceptions of NOS, continued

Author	Year	Participants	Intervention	Assessment	Design
Palmquist & Finely	1997	Pre-service teachers	Pre-service methods course	Researcher Developed Questionnaire Interviews, student work	Pre and post test
Abd-El-Khalick & Lederman	2000	College students Pre-service teachers	History of Science courses	Open-ended questionnaire, interviews Course syllabi, Classroom Observations	Pre and post test
Moss, et al.	2001	Students, grades 9-12	Partnerships with scientists	Interviews Student Work Classroom Artifacts	Qualitative participant observation
Liu & Lederman	2002	Taiwanese students, grades 9 – 12	Six day summer camp	VNOS	Pre and post test
Sadler, et al.	2002	Students, grades, 9-12	Biology course	Open ended questions, interviews Critical thinking assessments	Exploratory
Zeidler, et al.	2002	Students, grades 9 –12 Pre-service teachers	None	Researcher developed survey Mediated Dialogues	Multi-stage exploratory
Abd-El-Khalick & Akerson	2004	Pre-service teachers	Elementary science methods course	VNOS Interviews	Pre and post test

Students' Conceptions

Multiple studies have focused on the views of students in K-12 schools. Students often confuse science with technology, many are open to the idea that science can build upon the notion of an interfering higher power, and they believe that scientists are capable of being completely objective (Ryan & Aikenhead, 1992). Most students are not able to separate theories from evidence or describe the relationship between the two (Leach, et al, 1997; Rubba, et al., 1981). Generally, they do not understand that hypotheses can only by tested through falsification processes (Bady, 1979). K-12 students, especially those in North America, thought that scientists use a step-wise scientific method in their research (Griffiths & Barman, 1995; Ryan & Aikenhead, 1992), as have pre-service teachers who have been exposed to NOS instruction (Palmquist & Finley, 1997). Students are also unlikely to understand the tentative aspects of NOS (Griffiths & Barman, 1995; Rubba, et al., 1981).

Studies that focused on the effects of curricula on individuals' understandings of NOS have yielded mixed results. The Biological Sciences Curriculum Study (BSCS) curriculum reported to address NOS more effectively than traditional textbook curricula. However, middle school students taught by teachers using the BSCS did not answer NSKS questions better than those students taught by traditional methods (Meichtry, 1992). College students, however, enrolled in an undergraduate course that focused on STS issues showed more improvement in NOS views than students enrolled in a traditional physics course (Rubba, et al., 1996).

Teachers' Conceptions

In studies where teachers' and students' conceptions of NOS have been compared, teachers have had more acceptable views of NOS than their students (Lederman & Druger, 1985). Teachers with acceptable views of NOS, however, were unable to improve their students' views of NOS any more than teachers with less acceptable views (Lederman & Druger, 1985). This might be due to teachers' use of language, as this has been documented as making a difference in the development of students' NOS views (Zeidler & Lederman, 1989).

Coursework in the history of science, thought to be useful in the development of preservice teachers views of NOS, has been shown to be ineffective, especially if it does not include explicit NOS instruction (Abd-El-Khalick & Lederman, 2000). Earlier work with teachers suggested that instruction in the history of science developed teachers' understandings of NOS (Lavach, 1969). Explicit instruction in NOS is now thought to be a key aspect in developing individuals' views (Abd-El-Khalick & Akerson, 2004).

Developing NOS Understandings

As a result of the many studies of teacher and student NOS understandings, numerous suggestions have been made regarding the development of NOS understandings in teachers and students.

Student Development

NOS advocates have argued for exposing students to the history of science during science instruction to help them better appreciate the role of adapting to unexpected circumstances that arise during scientific investigations (Moss, et al., 2001). In other cases, researchers argue that students may also benefit from NOS instruction that is designed to address specific aspects of NOS while also teaching content. For example, McKinney & Michalovic (2004) designed science instruction that included the historical influences that took place in the development of the periodic table, while others incorporated historical components of the development of a model of DNA (Clough & Olson, 2004) and evolution instruction (Farber, 2003; Narguizian, 2004). Laboratory activities that explicitly address NOS have been developed for chromatography, mystery powders (Colburn, 2004) and mitosis (Lederman & Lederman, 2004). Others have worked to develop case studies that teachers can use to develop students' understandings of the limits of scientific knowledge (Clough, 2005; Guinta, 2001) and the role of error in science (Allchin, 2001). In another study, Biology professors assigned students the task of critically analyzing advertisements as a way to reinforce NOS concepts (Rutledge, 2005).

Researchers have also suggested that students' views of NOS will improve when students are given an opportunity to participate in authentic science experiences. Bell, et al. (2003) conducted a study to evaluate the hypothesis that participation in science research projects improves students' scientific literacy. This study involved 10 high school students participating in an 8-week science and engineering summer apprenticeship. Each student was given the opportunity to design research questions, collect, and analyze data. Prior to and immediately following the apprenticeship, students were given a modified version of the VNOS-B (Abd-El-Khalick, et al., 1998). Prior to the summer experience, the students' conceptions of NOS were inconsistent with the desired understandings. There was little evidence of change during the course of the 8-week apprenticeship. All of the students cited scientists' personal bias as the reason for scientists arriving at different conclusions for the same phenomena. The experience reinforced prior misconceptions about NOS, such as a belief that scientists follow a single scientific method. Researchers felt that if students had been given an opportunity to reflect on the experience in a larger context, reflective of the way scientists generate knowledge, a greater improvement in their NOS understandings might have been found (Bell, et al., 2003).

A long-standing assumption in science education is that students who participate in science activities will learn the desired aspects of NOS, even if the development of NOS understandings is not an explicit goal of instruction (Abd-El-Khalick, Bell, & Lederman, 1998). One of the problems with this implicit approach is that it fails to address the reflective thinking required to develop understandings of NOS (Bartholomew, Osborne & Ratcliffe, 2004). Researchers have noted that when students are left on their own to draw the connections between what they are learning to its implications for NOS, they cannot do so without explicit help from the teacher (Meichtry, 1992). Furthermore, studies have noted that the mere participation in research studies as part of a project-based class is not enough to develop full understandings of NOS (*c.f.* Moss, et al., 2001).

Teacher Development

Throughout the science education literature, the inclusion of history and philosophy of science in preservice teacher education coursework has been recommended (Abimbola, 1983; Andersen, Harty & Samuel, 1986; Behnke, 1961; Robinson, 1969; Wandersee, 1985) or as a part of a graduate program (Eichinger, et al., 1997). One proposal argues that teacher education could expose teachers to NOS through the use of typical classroom incidents, such as unexpected laboratory results or discussions of the moral and ethical conduct of scientists (Nott & Wellington, 1995). According to Coll, et al., (2005) teachers who have a strong understanding of NOS and its implications for pedagogy are more aware of the variety of mental models students may construct to explain scientific phenomena. Robinson (1969) suggested that with a better background in the philosophy of science, teachers may be less likely to split science into process and product.

Loving (1991) surveyed 17 institutions with undergraduate science teacher preparation programs in an effort to understand the emphasized philosophical positions. Results showed general lack of attention given to the philosophy of science. Furthermore, Loving (1991) found that only one of the ten texts used in methods courses contained a "balanced portrayal of science (p. 828)." The suggestions to include courses in the history and philosophy of science rest on an assumption that all teachers have the ability to pay attention to these ideas and reflect on their relationships to society (Manual, 1981).

Researchers have also suggested that teachers need to be better trained in methods to engage their students in meaningful dialogue that supports students' epistemic reasoning (Bartholomew, Osborne & Ratcliffe, 2004). If teachers are given opportunities to create their own conceptual model for NOS in preservice education, then they may be more willing to incorporate NOS in their science teaching (Moss, et al., 2001). Additionally, it has been suggested that if NOS objectives were embedded within science courses (Brickhouse, 1991; Carey & Stauss, 1968; Lederman & Latz, 1995), courses of learning theory, and clinical practice (Brickhouse, 1991), then teachers' views of NOS may develop more toward the desired understandings. It has long been recognized that traditional methods of training teachers do not provide them with adequate exposure to the philosophy of science and that without these understandings, teachers may not fully understand what is meant by phrases such as 'scientific inquiry' (Herron, 1969).

In a study designed to assess the effectiveness of explicit NOS education on preservice elementary teachers' NOS understandings, Akerson, et al., (2000), examined 25 undergraduate and 25 graduate students enrolled in science methods courses. NOS instructional activities were designed to explore the relationship between theories and laws, the differences between observation and inference, the empirical, creative, tentative, and imaginative NOS, theory-ladenness, and social and cultural embeddedness in NOS. An open-ended questionnaire, similar to the VNOS (Abd-El-Khalick, et al., 1998; Lederman & O'Malley, 1990; Lederman, et al., 2002), was given to the participants at the beginning and end of the course. This questionnaire was followed up with interviews. Both undergraduate and graduate students demonstrated improvement in their NOS views, although the researchers felt that more improvement was possible (Akerson, et al., 2000).

Discussion

The studies examined in this review of NOS literature demonstrate that the development of understandings of NOS has been a topic of extensive focus within the science education literature for the past 45 years. Although standards documents such as the *Benchmarks for Science Literacy* (AAAS, 1993) and the *National Science Education Standards* (NAS, 1996) have been published and widely referenced, the impact these standards have had on actual classroom practice remains elusive. In fact, science pedagogy remains very similar to the teaching methods used when these calls for the development of scientific literacy were initially made. This reason for this mismatch between reform goals and pedagogical strategies is a pertinent question for further research.

The multitude of assessments designed to measure NOS understandings has also complicated the NOS debate. The assessments were written to evaluate the views of students, teachers, and/or scientists without a clear definition of the expectation of what their views ought to be, although these definitions have since been articulated. Although it was recognized that the philosophers of science would describe the most complete conceptions of NOS, these understandings have been shown to be too complex for inclusion in K-12 science education. Nevertheless, the philosophical perspectives were the basis for the early NOS instruments and items written from the philosophy of science literature were later judged as inadequate for measuring student understandings.

The mismatch between assessment and learning was partly attributed to the differences between the meaning the researchers ascribed to the assessments items and their interpretations by students and teachers. While assessments like the VNOS (Abd-El-Khalick, 1998; Lederman & O'Malley, 1990; Lederman, et al., 2002) attempt to address this problem with open-ended questions and interviews of subsamples of students, it is still possible that the researchers may misinterpret the written answers of the larger majority of respondents not interviewed. Furthermore, the open-ended question/interview design makes the assessment too cumbersome for use in studies with large numbers of participants. The VOSTS (Aikenhead & Ryan, 1992), the only instrument that included interviews with thousands of students, is built on students' views of NOS, and whose multiple-choice design is well suited for use with large research studies.

Perhaps one of the difficulties facing the NOS movement is that its concepts are confounded with other goals in science education. NOS has been associated with the development of scientific literacy, inquiry-style instruction, and STS curricula. NOS is such a fundamental part of science that it may seem a burden for teachers to explicitly address its applications during instruction. Yet, as many of these articles have explained, NOS is the foundation of science and as such, it is broadly applicable. It seems possible that in an era of high teacher accountability, the addition of such a big, overarching idea may seem like an add-on to an already full and hurried curriculum.

Additionally, NOS' foundation in the philosophy of science requires a great deal of reading and study for full understanding. It is possible that the debates within the philosophy of science community are typically ill-suited to the cognitive development of high school students or to the science teacher education curriculum. Nevertheless, deeper understanding of the tenets of NOS and their significance to modern science are made clearer through the reading and discussion of philosophy of science. There is strong evidence, however, that philosophy and history of science coursework is not a significant part of most teachers' professional preparation. Although there have been suggestions for the explicit teaching of NOS objectives in methods courses, there has not been a discussion of the requisite level of understanding necessary for teachers. Clarity has been developed regarding the necessary outcomes for students, but no conclusions have been drawn about the degree to which teachers need a complex understanding of NOS. Although NOS is mentioned as part of NSTA's *Standards for Science Teacher Preparation* (2003), the standards fail to recommend a course of study, instead they offer only books that students' should consider reading and assignments professors' could provide their students.

Now that the definition of NOS for K-12 education has been established in the literature (Lederman, et al., 2002; McComas & Olson, 1998; Osborne, et al., 2003), future research can explore potential reasons for difficulties in developing these understandings in students and teachers. Studies can be conducted to further explain the differences in the educational needs of future scientists and consumers of science and the role that NOS instruction might play in curricula designed for these groups. Additionally, research is needed to examine the teachers' views of the standards documents and how these goals are used as resources for planning science instruction. It remains unclear why researchers have had difficulty measuring changes in NOS following instruction. Are there underlying cognitive skills needed to fully understand the nature of scientific inquiry? At what ages and grade levels are students developmentally ready to learn NOS? To what degree does the general public need to understand the unique characteristics of NOS? Would educating the public about NOS improve their abilities to make decisions about science-related issues that arise in everyday life? From a curriculum standpoint, would it be useful for students to examine ways of knowing across different content domains? If science as a way of knowing were juxtaposed to writing as a way of knowing, could we enhance students' abilities to understand the limits of scientific inquiry? While NOS has been a frequent topic of discussion and research in the science education community, there are plenty of questions that remain unanswered and that invite future inquiry.

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USING THE VIEWS-ON-SCIENCE-TECHNOLOGY-SOCIETY INSTRUMENT TO COMPARE NATURE OF SCIENCE VIEWS BETWEEN GROUPS

What is science, how does it differ from other disciplines of inquiry, and how do we teach K-12 students to appreciate the differences? These questions lie at the heart of science education and are questions that educators have struggled with for years. Understanding what makes science unique and understanding the processes of scientific inquiry can help students make informed decisions about science applications in their lives. Some researchers have argued that by having students study the nature of science (NOS), students will then be able to use these perspectives when making decisions about complex issues that can be informed by science (Sadler, et al., 2002; Zeidler, et al., 2002; Zeidler, et al., 2005). However, if NOS is going to be included in the reform of science education, then educators need a clear definition of the nature of science (NOS) accompanied by valid and reliable assessments of NOS. This paper explores the commonalities of NOS constructs across different researchers and investigates the Views-on-Science-Technology-Society (Ryan & Aikenhead, 1992) instrument as an assessment tool for large-scale research and evaluation.

Although the *Benchmarks for Science Literacy* (American Association for the Advancement of Science, 1993) and the *National Science Education Standards* (National Academy of Sciences, 1996) have sought to define what students ought to know and be able to do while articulating a teaching philosophy of "science for all," uncertainty about these issues remain. Some science educators have interpreted teaching science for all as teaching for scientific literacy (Shamos, 1995), of which nature of science (NOS) is considered a critical component (Meichtry, 1992; Rubba, et al., 1981). Can we really expect all students to understand how science knowledge is tentative, historic, and culturally bound simultaneously? Understanding these issues can inform our development of curricula, standards, and individual lessons.

Some researchers have argued that understanding NOS is linked to the development of scientific literacy (Meichtry, 1992; Rubba, et al., 1981), inquiry instruction (Bell, 2003), and instructional practices in K-12 classrooms (Lederman, 1987). Others maintain that NOS is critical for the preparation of science teachers (Abd-El-Khalick, et al., 2002; Akerson, 2002; Bell, 2003;). One argument for the inclusion of NOS in the curriculum is the development of an understanding of the epistemological underpinnings of science would help citizens evaluate scientific claims against other knowledge claims when making complex decisions (Bell, 2003; Sadler, et al., 2002; Zeidler, et al., 2005).

Defining the Nature of Science

Philosophers of science may be concerned with the degree to which the philosophy, history, and sociology of science is simplified into the NOS objectives for K-12 education (Alters, 1997). Despite these concerns, science educators are comfortable that these simplified characteristics are adequate given the needs of K-12 students (Smith, et al., 1997). An analysis of NOS descriptions across multiple studies shows there is a common set of characteristics that sets science apart as a unique way of knowing. The present study included an examination of international standards documents (McComas & Olson, 1998), literature on the philosophy of science (Lederman, et al., 2002), and experts' views of NOS (Osborne, et al., 2003). Osborne, et al. (2003) first proposed a unified description of NOS through an alignment between the findings of their study and the concepts identified by McComas & Olson (1998) (see table 3). McComas & Olson's (1998) and Osborne, et al.'s, (2003) NOS concepts share common elements with the tenets of NOS described by Lederman, et al., (2002). These common NOS elements include the following: certainty of knowledge (tentativeness), empirical evidence, replicability of experiments, explaining and predicting, creativity, science is socially and historically embedded, and science involves diverse thinking. Although this list is not exhaustive, it does represent common perspectives of different scholars.

Table 3: *Components of the nature of science*

	NOS Concepts		
Characteristic	McComas & Olson (1998)	Lederman, et al. (2002)	Osborne, et al., (2003)
Tentative	Scientific knowledge is tentative (8)[1].	Scientific knowledge is tentative.	Science & Certainty: Appreciate why much scientific knowledge…is well established and beyond reasonable doubt, and why other scientific knowledge is more open to legitimate doubt (p.701).
Empirical	Science relies on empirical evidence (6).	Scientific knowledge is empirical.	Analysis & Interpretation of Data: The practice of science involves skillful analysis and interpretation of data (p. 702).
Replicable	Scientists require replicability and truthful reporting (7).	There is not a universal recipe-like method for doing science.	Scientific Method & Critical Testing: Science uses the experimental method to test ideas, and in particular, about certain basic techniques, such as the use of controls. The outcome of a single experiment is rarely sufficient to establish a knowledge claim (p.702).
Explanative & Predictive	Science is an attempt to explain phenomena (7).		Hypothesis & Prediction: Scientists develop hypotheses and predictions about natural phenomena. This process is essential to the development of new knowledge claims (p. 702).
Creative	Scientists are creative (6).	Scientific knowledge is the product of human imagination, inference, and creativity.	Creativity: Science is an activity that involves creativity and imagination as much as many other human activities (p. 702). Science & Questioning: An important aspect of the work of a scientist is the continual and cyclical process of asking questions and seeking answers, which then lead to new questions (p. 703).
Historic & Cultural	Scientific ideas have been affected by their social and historical milieu (6).	Science is socially and culturally embedded.	Historical Development of Scientific Knowledge: Students should be taught some historical background to the development of scientific knowledge (p. 701).
Diverse		There is not a universal recipe-like method for doing science.	Diversity of Scientific Thinking: Science uses a range of methods and approaches and that there is no one scientific method or approach (p. 702).

[1] Numbers in parentheses indicate the number of standards documents including this idea (McComas & Olson, 1998).

Tentativeness of science knowledge was found, for example, in all of the definitions of NOS. McComas and Olson (1998) reported that each of the eight science standards documents they reviewed mentioned the tentativeness of scientific knowledge. Lederman, et al., (2002) argued that a key component of NOS is the idea that scientific knowledge claims have a tentative aspect. Osborne, et al., (2003) described this feature of NOS by stressing there are some knowledge claims in science that are more firmly established than others. As each of these studies show, there is greater commonality between these NOS concepts than differences. While researchers may describe NOS with tenets (Lederman, et al., 2002) or questions (Clough, 2005), these characteristics are now common enough that the debate regarding the definition of NOS for K-12 instruction has largely been settled (McComas, 2005a; McComas, 2005b) and NOS is widely considered a fundamental and necessary component of K-12 science curriculum (Bartholomew, Osborne, & Ratcliffe, 2004).

Developing NOS understandings

Although there is growing support for the teaching of NOS as a critical component of science education, studies have shown that few teachers hold these views of science (Akerson, Abd-El-Khalick, & Lederman, 2000). Summer institutes, designed to help in-service teachers develop the desired NOS understandings, have reported mixed results in the effectiveness of changing NOS concepts (Billeh & Hassan, 1975; Lavach, 1969; Scharmann & Harris, 1992; Welch & Walberg, 1967-1968). Pre-service teacher education has failed to consistently produce teachers with fully developed NOS understandings (Brickhouse, 1991; Carey & Stauss, 1968; Palmquist & Finley, 1997). Studies of high school students' views of NOS have revealed that generally, high school students' do not understand NOS concepts and furthermore, interventions have failed to change their understandings of NOS (Bady, 1979; Bell, Blair, & Crawford, 2003; Dotger, et al., 2005; Griffiths & Barman, 1995; Leach, et al., 1997; Liu & Lederman, 2002; MacKay, 1971; Meichtry, 1992; Moss, et al., 2001; Ryan & Aikenhead, 1992; Rubba, et al., 1991; Sadler, et al., 2002;).

Why are science educators having such little success teaching students about the nature of scientific inquiry? One reason that has been proposed is that teachers are not prepared in ways that teach them about the uniqueness of science and the elements of the nature of science. A number of researchers argue that teachers should have coursework in the history and philosophy of science as a way to develop an understanding of NOS (Abimbola, 1983; Andersen, Harty & Samuel, 1986; Behnke, 1961; Robinson, 1969; Wandersee, 1985) and those that focus on explicit instruction appear to impact teachers' views (Abd-El-Khalick, 2005). Researchers also maintain that if science content courses address NOS, teachers' views would improve (Brickhouse, 1991; Carey & Stauss, 1968; Lederman & Latz, 1995). Most recently, efforts to expose teachers to explicit NOS instruction in methods coursework seems to help them develop more informed views (Akerson, et al., 2000) and efforts have been made to design activities that help teachers explicitly teach NOS to their students (Clough & Olson, 2004; Colburn, 2004; Farber, 2003; Lederman & Lederman, 2004; Narguizian, 2004). Consensus is growing that making NOS an explicit cognitive outcome for instruction is a key component to developing NOS understandings (Abd-El-Khalick, Bell, & Lederman, 1998; Bartholomew, Osborne, & Ratcliffe, 2004; Meichtry, 1992; Moss, et al., 2001).

Little is currently known about how understandings of NOS are related to educational level or content background. Welch & Pella (1967-1968) evaluated the views of teachers, high school students and scientists using the Science Process Inventory (SPI) and other tests of mental ability. They found that scientists outperformed science teachers, who in turn outperformed high school students (Welch & Pella, 1967-1968). This finding was later confirmed in a comparison of views of teachers and their students using a different assessment (Lederman, 1986). Kimball (1967-1968) used the Nature of Science Scale to compare the views of scientists, philosophers, and classroom teachers. When controlling for the highest degree obtained, Kimball found no differences between the NOS views of scientists and teachers. However, the philosophers performed significantly better than both groups (Kimball, 1967-1968).

Challenges in Assessing Students' Knowledge of NOS

There have been a number of problems encountered as researchers have sought to assess students' knowledge of NOS as well as any changes in NOS knowledge. Seven different assessments have been developed for assessing NOS over the last 39 years: the *Science Process Inventory* (SPI) (Welch & Pella, 1967-1968), the *Nature of Science Scale* (NOSS) (Kimball, 1967-1968), the *Test on Understanding Science* (TOUS) (Welch & Walberg, 1967-1968), the *Nature of Scientific Knowledge Scale* (NSKS) (Rubba, 1977), the *Conceptions of Scientific Theories Test* (COST) (Cotham & Smith, 1981), the *Views-on-Science-Technology-Society* (VOSTS) (Ryan & Aikenhead, 1992), and the *Views on the Nature of Science* (VNOS), forms A, B, and C (Lederman & O'Malley, 1990; Abd-El-Khalick, et al., 1998; Lederman, et al., 2002). Of these instruments, the SPI, NOSS, TOUS, NSKS, and COST have all been criticized as suffering from a lack of consistent interpretation by the participants answering the questions, a lack of consistent representation of the philosophy of science and a failure to reflect the ever-evolving understanding of NOS (Lederman, et al., 1998; Lederman, et al., 2002).

One assessment, the VOSTS, has emerged as a comprehensive assessment tool that is sufficiently inclusive of the modern definitions of NOS and has been used in multiple studies (Aikenhead, et al., 1989; Aikenhead & Ryan, 1992; Clough, 2001). According to Aikenhead & Ryan (1992), the validity of VOSTS items emerges from being grounded in student views. This naturalistic approach values the perspectives of the students, rather than those of philosophers of science or science educators who specialize in NOS. As noted by the authors of the items, "the validity of the process and of the final instrument lies in the trust with which subsequent researchers place in the process" used to develop the questions (Aikenhead & Ryan, 1992, p. 488). Since the VOSTS has been used as a research instrument in at least 14 research studies (Aikenhead, 1987; Botton & Brown, 1998; Haidar, 2000; Lin & Chen, 2002; Mbajiorgu, 2001, 2002; Rubba, Schonewag Bradford, & Harkness, 1995; Ryan, 1987; Ryan & Aikenhead, 1992; Schallies, 2002; Schonewag Bradford, Rubba, & Harkness, 1995; Tedman & Keeves, 2001; Zoller, et al., 1990, 1991), the question development process has been accepted as a valid process for specifying the content of NOS (Clough, 2001).

During the construction of the VOSTS items, Ryan and Aikenhead, (1992) were interested in determining the degree to which the items accurately captured students' views on STS issues. In order to determine this, the multiple-choice items included in the VOSTS were compared with other modes of assessing NOS understandings: Likert-type responses, paragraph responses, and semi-structured interviews. Semi-structured interviews resulted in the least amount (five percent) of ambiguity between the students' written responses and their interviews. For Likert-type responses, the rate of ambiguity increased to 80%, while paragraph responses reached a level of 35%-50% ambiguity. The results of the multiple-choice items that eventually became the VOSTS resulted in ambiguity between written response and interview response 15-20% of the time. The use of the multiple-choice VOSTS questions results in reduced ambiguity from Likert-type responses and from open-ended questions, while still providing an assessment process that is manageable with a large number of respondents (Aikenhead, 1988). This reduction in ambiguity for evaluating student responses increases the likelihood that researchers will correctly interpret the results of the VOSTS, improving the validity of the instrument.

The VOSTS was developed through a step-wise process including the analysis of science education standards and literature, the development of question prompts, and testing and retesting these prompts with thousands of high school students (Ryan & Aikenead, 1992). The resulting assessment includes 114 items that examine students' views of the definition of science, the influence of society on the scientific enterprise, the social relationships between scientists and their effects on the outcomes of science, and the epistemology of science. The VOSTS was designed to provide a pool of valid items that could be tailored to specific interests of teachers and researchers.

The VOSTS has been used in the past with participants with a wide variety of backgrounds. During the development of the questions and early research, the participants were Canadian high school students (Aikenhead, 1987; Ryan, 1987; Ryan & Aikenhead, 1992). Further research has been conducted by using the VOSTS with high school students in Nigeria, Germany, and the United States (Mbajiorgu & Ali, 2002; Rubba, et al., 1995; Schallies, 2002; Zoller, et al., 1991). The VOSTS has been used to assess the views of undergraduates in England, Taiwan, and Nigeria (Botton & Brown, 1998; Lin & Chen, 2002; Mbajiorgu & Iloputaife, 2001) as well as with professors in Arab countries (Haidar, 2000).

Reliability. Although Aikenhead & Ryan (1992) did not address the reliability of the VOSTS items, Botton and Brown (1998) have conducted a study to establish the reliability of selected items. Fifteen items from the VOSTS were used with undergraduates enrolled in a yearlong university course. Students were given the 15 items and then were retested one month afterward. Pearson chi-square values were calculated by comparing each student's first answer to their second one. All items tested were found reliable, with an average reliability of .72 (Botton & Brown, 1998).

Goal of the Study

This study seeks to determine if differences in NOS views can be identified using the Views-on-Science-Technology-Society (VOSTS) instrument (Aikenhead & Ryan, 1992) for individuals with varying educational backgrounds and content expertise. The present study extends earlier work to include a quantitative scoring protocol and includes a wider variety of individuals. In addition, this study investigates the effect of content knowledge and years of education as factors for explaining variance in VOSTS responses. To achieve these goals, an alignment of VOSTS items with the NOS literature was conducted and a scoring procedure for analyzing participants' responses was developed.

Methodology

Selection of VOSTS questions

An analysis of 14 previous studies that used the VOSTS was conducted to see which of the 114 original questions were most often used in research (Aikenhead, 1987; Botton & Brown, 1998; Haidar, 2000; Lin & Chen, 2002; Mbajiorgu, 2001, 2002; Rubba, Schonewag Bradford, & Harkness, 1995; Ryan, 1987; Ryan & Aikenhead, 1992; Schallies, 2002; Schonewag Bradford, Rubba, & Harkness, 1995; Tedman & Keeves, 2001; Zoller, et al., 1990, 1991). It was hoped that if a group of questions were used at least 50% of the time, this might indicate some agreement in the research community that these questions adequately reflected the understandings of NOS most desired by science education researchers. An analysis of these 14 studies revealed no such commonality.

The question selection then proceeded with an analysis of the literature and the determination of the most important aspects of NOS as identified by Osborne, et al., (2003), McComas and Olsen (1998), and Lederman, et al., (2002). These aspects of NOS are presented in Table 4. Eight questions from the VOSTS that best align to these NOS principles were selected for further study.

Table 4: *Alignment of VOSTS questions to NOS characteristics*

Characteristic	VOSTS question
Tentative	90411: Change in scientific knowledge
Empirical	70212: Scientists disagree
	90111: Influence of theory
Replicable	90611: Scientific method
Explanative & Predictive	10111: Defining science
Creative	90211: Models as accurate representations
Historic & Cultural	90921: Influence of supernatural
Diverse	70721: Scientific method & culture

Rating process. A five-person panel of science educators reviewed the VOSTS items for NOS alignment and scored each item. Similar to the procedure followed in other studies (Rubba, et al., 1996; Tedman & Keeves, 2001; Vazquez-Alonso & Manassero-Mas, 1999;) each panel member was asked to rate the single most acceptable response to the stem with 3 points, rate the reasonable responses with 2 points, and rate the unacceptable answers with 1 point. Responses indicating that the optional choices were not applicable received 0 points. Each member of the panel rated the responses independently. The individual ratings were collected and recorded by the author.

Following the completion of the rankings, Kendall's W test of concordance was used to establish the degree of response agreement between the members of the panel for each question. The results of this analysis, as well as the degree of agreement as described by Landis & Koch (1977), are indicated in the Table 5.

Table 5: *Kendall's W coefficients of concordance*

Question	Coefficient of Concordance	Degree of Agreement
10111	.879	Almost perfect
70212	.879	Almost perfect
70721	.783	Substantial
90111	.848	Almost perfect
90211	.948	Almost perfect
90411	.940	Almost perfect
90611	.885	Almost perfect
90921	.920	Almost perfect
All questions	.869	Almost perfect

Note: The terms used to indicate degree of agreement were identified by Landis & Koch, 1977.

Each expert's ratings were shared with the panel and discussion followed in order to come to a group agreement on the ratings. The final agreed upon rankings of the panel are described below Tables 6 through 13; the points for each question are shown in parentheses next to the response. The rating rationale is provided in order to allow other researchers to use this rating system when using the VOSTS as a large-scale assessment of NOS understandings. Since the final three responses are the same for each question, they were removed in order to conserve space.

Rationale of rankings

Table 6: *VOSTS Question 10111, with rankings*

Defining science is difficult because science is complex and does many things. But MAINLY science is:

Your position, basically: (Please read from A to K, and then choose one.)

A. a study of fields such as biology, chemistry and physics. (**2**)

B. a body of knowledge, such as principles, laws and theories, which explain the world around us (matter, energy and life). (**2**)

C. exploring the unknown and discovering new things about our world and universe and how they work. (**3**)

D. carrying out experiments to solve problems of interest about the world around us. (**2**)

E. inventing or designing things (for example, artificial hearts, computers, space vehicles). (**1**)

F. finding and using knowledge to make this world a better place to live in (for example, curing diseases, solving pollution and improving agriculture). (**1**)

G. an organization of people(called scientists) who have ideas and techniques for discovering new knowledge. (**1**)

The first item asked students to define science and although the panel agreed that no single response fully defined science, choice C was selected as the best response because it captured science as an active process that continues from one day to the next. Choices A and B were considered to be too limiting and failed to address the active nature of science. Answer D was not selected as the best choice for two reasons. One, the panel recognized that not all of science progresses through experimentation and two, the phrase "of interest" was problematic since it failed to specify whose interests were taken into account.

Answers E – H were each given 1 point because these descriptions of science were even more limiting than the prior responses. Choice E seemed to more accurately describe technology, while choices F and G could have been used to generally describe other methods of finding or using knowledge or having new ideas. H was considered an unacceptable answer because while science may be difficult to define succinctly, defining science is part of the focus of the epistemology of science.

Table 7: *VOSTS Question 70212, with rankings*

When scientists disagree on an issue (for example, whether or not low-level radiation is harmful), they disagree mostly because they do not have all the facts. Such scientific opinion has NOTHING to do with moral values (right or wrong conduct) or with personal motives (personal recognition, pleasing employers, or pleasing funding agencies).

Your position, basically: (Please read from A to J, and then choose one.)

Disagreements among scientists can occur:

A. because not all the facts have been discovered. Scientific opinion is based entirely on observable facts and scientific understanding. (**1**)

B. because different scientists are aware of different facts. Scientific opinion is based entirely on a scientist's awareness of the facts. (**1**)

C. when different scientists interpret the facts differently (or interpret the significance of the facts differently). This happens because of different scientific theories, NOT because of moral values or personal motives. (**2**)

D. mostly because of different or incomplete facts, but partly because of scientists' different personal opinions, moral values, or personal motives. (**2**)

E. for a number of reasons — any combination of the following: lack of facts, misinformation, different theories, personal opinions, moral values, public recognition, and pressure from companies or governments. (**3**)

F. When different scientists interpret the facts differently (or interpret the significance of the facts differently). This happens mostly because of personal opinions, moral values, personal priorities, or politics. (Often the disagreement is over possible risks and benefits to society.) (**2**)

G. because they have been influenced by companies or governments. (**1**)

The panel felt that disagreements between scientists could occur for multiple reasons and that it was difficult to make a statement regarding the influence of fact or personal opinion on the disagreement. Therefore, the panel chose answer E as the most acceptable. Answers D and F were considered reasonable choices because they acknowledged that facts and other social factors were responsible for the decisions scientists made and these choices weighed in on the degree to which scientists considered the facts when stating a conclusion.

Table 8: *VOSTS Question 70721, with rankings*

A team of scientists in any part of the world (for example, Italy, China or Nigeria) would investigate the atom in basically the same way as a team of American scientists.

Your position, basically: (Please read from A to J, and then choose one.)

Scientists conduct their investigations in the same way all over the world:

A. because science is universal. All scientists use the scientific method regardless of where they live. (**1**)

B. because scientists share their views and ideas with each other. (**1**)

C. Every team of scientists has its own methods and ideas. This has nothing to do with the country they live in. Everyone is different. (**1**)

Scientists from different countries conduct their investigations differently:

D. because the way you do science depends on the technology available. (**2**)

E. because the way you do science depends on the technology available. But even though scientists use different technology, they use the same scientific method. (**2**)

F. because the way you do science depends on your education AND on the technology available. (**3**)

G. because of the different social conditions, resources, ideas and culture which affect everything, including the methods used by scientists. (**2**)

As a whole, the panel felt that scientists in different countries would conduct their investigations differently. For this reason, answer choices A – C were all considered unacceptable because they differed from this point of view. Answer choice F was selected as the best answer because education and technology were considered the most influential factors on the ways scientific investigations were conducted. While answer choice G reflects this sentiment, the panel was uncomfortable with the degree of openness of the response, as a result it was considered a reasonable answer. Answer choices D and E acknowledged science was conducted differently, but were given 2 points because the reasons for these differences were thought to be too narrow.

Table 9: *VOSTS Question 90111, with rankings*

90111. Scientific observations made by competent scientists will usually be different if the scientists believe different theories.

Your position, basically: (Please read from A to H, and then choose one.)

A. Yes, because scientists will experiment in different ways and will notice different things. (**3**)

B. Yes, because scientists will think differently and this will alter their observations. (**2**)

C. Scientific observations will not differ very much even though scientists believe different theories. If the scientists are indeed competent their observations will be similar. (**1**)

D. No, because observations are as exact as possible. This is how science has been able to advance. (**1**)

E. No, observations are exactly what we see and nothing more; they are the facts. (**1**)

The panel was confident that scientific observations are different based on different theories. Therefore, answers C, D, and E were considered unacceptable since they disagreed with this view. When choosing between A and B as the most acceptable answer, the panel chose answer A because they felt that different theories led most directly to different kinds of experimentation and were most comfortable with the idea that different observations were the result of different experiments. The panel acknowledged that when two scientists conduct the same experiment, they may record different observations based on their theoretical understandings. However, since answer choice B did not specify the role of experimentation, this answer choice was considered reasonable and given 2 points.

Table 10: *VOSTS Question 90211, with rankings*

Many scientific models used in research laboratories (such as the model of heat, the neuron, DNA, or the atom) are copies of reality.

Your position, basically: (Please read from A to J, and then choose one.)

Scientific models ARE copies of reality:

A. because scientists say they are true, so they must be true. (**1**)

B. because much scientific evidence has proven them true. (**1**)

C. because they are true to life. Their purpose is to show us reality or teach us something about it. (**1**)

D. Scientific models come close to being copies of reality, because they are based on scientific observations and research. (**2**)

Scientific models are NOT copies of reality:

E. because they are simply helpful for learning and explaining, within their limitations. (**2**)

F. because they change with time and with the state of our knowledge, like theories do. (**3**)

G. because these models must be ideas or educated guesses, since you can't actually see the real thing. (**1**)

The panel reached the greatest degree of agreement with this question. The panel felt strongly that scientific models are not copies of reality. Answer choices A, B, and C did not reflect that point of view and were each given 1 point. Answer choice D began to depart from the notion that models are copies of reality and noted that models were constructed based on observations and research. This was considered a reasonable answer. Response E was considered a reasonable answer because it noted that models had limitations. F was chosen as the best response since it recognizes that models change and did not contain any phrases that the committee found objectionable.

Table 11: *VOSTS Question 90411, with rankings*

Even when scientific investigations are done correctly, the knowledge that scientists discover from those investigations may change in the future.

Your position, basically: (Please read from A to G, and then choose one.)

Scientific knowledge changes:

A. because new scientists disprove the theories or discoveries of old scientists. Scientists do this by using new techniques or improved instruments, by finding new factors overlooked before, or by detecting errors in the original "correct" investigation. (**3**)

B. because the old knowledge is reinterpreted in light of new discoveries. Scientific facts can change. (**2**)

C. Scientific knowledge APPEARS to change because the interpretation or the application of the old facts can change. Correctly done experiments yield unchangeable facts. (**1**)

D. Scientific knowledge APPEARS to change because new knowledge is added on to old knowledge; the old knowledge doesn't change. (**1**)

The panel's ratings of this question resulted in a substantial level of agreement. The panel was confident that scientific knowledge actually changes, rather than the changes being a matter of appearance. As such, answer choices C and D were considered unacceptable and given 1 point each. Answer choice A was considered the most desirable response since it provided multiple reasons for the changes in scientific knowledge and described the change in knowledge most completely. Answer choice B was considered an acceptable response since it recognized that knowledge changes, yet the reasons for this change were less complete than what was offered in answer A.

Table 12: *VOSTS Question 90611, with rankings*

When scientists investigate, it is said that they follow the scientific method. The scientific method is:

Your position, basically: (Please read from A to M, and then choose one.)

A. the lab procedures or techniques; often written in a book or journal, and usually by a scientist. (**1**)

B. recording your results carefully. (**1**)

C. controlling experimental variables carefully, leaving no room for interpretation. (**1**)

D. getting facts, theories or hypotheses efficiently. (**1**)

E. testing and retesting — proving something true or false in a valid way. (**1**)

F. postulating a theory then creating an experiment to prove it. (**1**)

G. questioning, hypothesizing, collecting data and concluding. (**2**)

H. a logical and widely accepted approach to problem solving. (**3**)

I. an attitude that guides scientists in their work. (**2**)

J. Considering what scientists actually do, there really is no such thing as the scientific method. (**1**)

This question was rated with a substantial amount of agreement among the panel. Answer choices A through E were all considered to be too narrow to capture the breadth of activities that are considered to be a part of scientific methodologies. Similarly, answer choice J was considered inappropriate. Although it is recognized that one goal of NOS education is to help students understand there is not a single scientific method (Lederman, et al., 2002), it seemed inappropriate to suggest that there was no such thing as a scientific method. This seemed to imply that there was no characteristic that could be used to describe the kind of work a scientist does. Answer choice G was considered a reasonable answer even though it incorporated much of the traditional step-wise description of scientific methodology; it seemed more complete than the previous answer choices. Answer I was considered reasonable but not ideal because it was too broad. Answer H was considered to be the best answer because it mentioned the importance of being logical and did not specify a set of steps for a scientist to follow.

Table 13: *VOSTS Question 90921, with rankings*

Science rests on the assumption that the natural world can *not* be altered by a supernatural being (for example, a deity).

Your position, basically: (Please read from A to H, and then choose one.)

Scientists assume that a supernatural being will NOT alter the natural world:

A. because the supernatural is beyond scientific proof. Other views, outside the realm of science, may assume that a supernatural being can alter the natural world. (**3**)

B. because if a supernatural being did exist, scientific facts could change in the wink of an eye. BUT scientists repeatedly get consistent results. (**1**)

C. It depends. What scientists assume about a supernatural being is up to the individual scientist. (**1**)

D. Anything is possible. Science does not know everything about nature. Therefore, science must be open-minded to the possibility that a supernatural being could alter the natural world. (**1**)

E. Science can investigate the supernatural and can possibly explain it. Therefore, science can assume the existence of supernatural beings. (**1**)

The panel agreed that science needed to operate as if a supernatural being was beyond the realm of science and rated answer A with 3 points. All other answers were considered unacceptable because they entertained the influence of a supernatural being in science.

Following the scoring by the expert panel, the eight VOSTS items were given to participants from a wide variety of majors, ages, and educational levels to evaluate how VOSTS response varied according to these factors.

Participants

Three hundred and twenty three individuals representing multiple education levels and content backgrounds participated in this study. High school students, undergraduates, graduate students and post-doctoral fellows were recruited from multiple institutions using a variety of methods described below. This study is part of a larger on-going investigation of the cognitive and developmental basis of NOS understandings. The groups selected represent cross-sections of both a developmental continuum and content backgrounds.

Recruitment

High school students were recruited from the classes of teachers that volunteered to participate in the study. High school students were drawn from two schools, one public, rural school and one charter, rural school in a southeastern state of the US. Students in both schools performed above the state average on tests in Biology and Chemistry during the 2004-2005 academic year (www.ncpublicschools.org). Table 14 indicates the demographics of the participating high schools.

Table 14: *High school student demographics (percentages)*

School	White	Black	Hispanic	Asian/Pacific Islander	Mutli-Racial	Economically Disadvantaged
Charter	97%	1%	1%	1%	0%	0%
Public	81%	14%	1%	1%	2%	21%

College students were recruited from four universities; two private and two public. The student enrollment in the public universities was 22,754 and 16,525 students, respectively. For the private institutions, the enrollment was 6,301 and 4,272 students

(College Foundation of North Carolina, 2005). Some undergraduate students volunteered for the study in order to receive participation credit in one of their courses. They were informed of the study through course websites and instructor announcements. Other undergraduates, graduate students, and post-doctoral fellows who participated were contacted by email. The email addresses were found on departmental websites and by contacting the registrar's office of participating institutions. The email messages described the purpose of the study, the length of time involved, the tasks required during participation, and entrance into a drawing when participation was complete. Individual appointments were scheduled with each volunteer. Table 15 shows the number of individuals contacted, their year of study, and the number of volunteers from each group.

Table 15: *Study participants, by year of education*

Individuals Contacted (N = 3037)	Year	Participants (N = 323)
70	High School Freshmen	54
76	High School Juniors	37
1895	Undergraduate Freshmen	84
450	Undergraduate Seniors	72
408	Masters' Students	54
146	Post-Doctoral Fellows	22

Demographics

Fifty-eight percent of the study participants were female. Participants identified themselves as Black (5%), Asian (6%), Hispanic (2%), 86% White, and 1% as other. All college-aged participants were asked to report their major. Since this study was conducted in the early weeks of the fall semester, undergraduate freshmen were classified as not having a major during data analysis due to the multiple major changes (2-4) that students experience during their first two years in higher education institutions (Registration and Records, 2005) and the limited time they have been enrolled in higher education.

Undergraduate seniors, masters' students, and post-doctoral fellows represented 42 different majors. These majors were grouped into categories, since in some cases one individual represented a major. Twenty-three percent of the advanced collegiate participants were philosophy majors. Forty percent of these collegiate participants majored in the sciences, distributed over 22 majors in the areas of biological science (47%), physical science (29%), earth science (12%), applied science (5%), and natural resources (7%). Thirty-seven percent of the advanced students majored in the humanities, representing 19 majors that were grouped into business (6%), education and psychology (20%), general studies (2%), and literature & social studies (72%).

Analysis

Item responses were rated according to the scoring scheme agreed upon by the panel. Given the methods used to construct the VOSTS items, it is not reasonable to add the points the participant was given for each question in order to arrive at an overall score. VOSTS responses were treated as ordinal variables. Since the frequency of 0 and 1 responses was small for most questions, these response categories were collapsed during analysis. Differences between groups based on educational level and content background were determined separately for each of the eight questions.

Effect of Educational Level on VOSTS response

In order to evaluate the effect of educational level on VOSTS response, the participants were grouped into four categories: high school students, undergraduate freshmen, undergraduate seniors, and graduate students. Since the categories represented a mean difference of 3 years of schooling, these categories were ranked from 0 to 3 and treated as quantitative variables. Ordinal logistic regression was used to determine if the distribution of VOSTS responses shifted from a majority of unacceptable responses among students in high school to a greater majority of reasonable[2] responses among graduate students. The Wald Chi-square statistic was used to test the null hypothesis of no differences in the distribution of student responses by educational level. Table 16 presents the VOSTS items, a brief item description, the frequency of each response for each category, the mean response for each category, the value of the Chi-square test statistic, and the associated one-sided p-value.

[2] "Reasonable" refers to scores that were rated as consistent with expert views of NOS.

Table 16: *Ordinal regression results for the effect of Education on VOSTS response*

	Item	Education category	VOSTS Response 1	2	3	Mean	Test Statistic Wald	*P*<
10111	Defining science	HS students	19	52	29	2.10	.129	.359
		College freshmen	10	65	26	2.17		
		College seniors	14	56	31	2.17		
		Graduate students	13	67	20	2.01		
70212	Why scientists disagree	HS students	39	32	30	1.92	11.821	.001
		College freshmen	19	33	48	2.44		
		College seniors	13	25	63	2.25		
		Graduate students	12	33	55	2.43		
70721	Scientific method & culture	HS students	55	38	8	1.54	6.137	.007
		College freshmen	28	65	8	1.80		
		College seniors	47	42	11	1.64		
		Graduate students	28	62	11	1.83		
90111	Influence of theory on observation	HS students	27	30	44	2.13	4.527	.984
		College freshmen	35	38	27	1.92		
		College seniors	36	42	22	1.88		
		Graduate students	41	30	29	1.88		
90211	Models as accurate representations	HS students	46	42	9	1.59	21.203	.001
		College freshmen	27	58	15	1.89		
		College seniors	22	61	17	1.86		
		Graduate students	11	70	20	2.09		
90411	Change in scientific knowledge	HS students	23	22	55	2.25	1.676	.098
		College freshmen	16	23	62	2.45		
		College seniors	15	36	49	2.39		
		Graduate students	26	37	37	2.11		
90611	Scientific method	HS students	49	39	12	1.63	3.032	.041
		College freshmen	21	66	13	1.93		
		College seniors	32	56	13	1.81		
		Graduate students	29	61	11	1.82		
90921	Influence of supernatural	HS students	76	0	23	1.47	5.498	.010
		College freshmen	52	0	48	1.98		
		College seniors	53	3	44	1.92		
		Graduate students	57	3	41	1.84		

There were significant differences in the distributions of scores for education levels for most of the VOSTS items. For each question with a significant Wald statistic, the high school mean is the lowest of the means. This finding suggests that high school students' conceptions of NOS are different than those of college students for five of the eight VOSTS items.

Effect of College Major on VOSTS response

The VOSTS response data were analyzed by major (science, humanities, and philosophy) with an ordinal logistic regression model. Only undergraduate seniors, masters' students, and individuals with doctorates were included in this stage of analysis. Since college major is not a variable that can be scaled, it was treated categorically. The resulting Wald statistics compare one major against the other two. Only two statistics are presented since the third comparison is redundant. The frequencies of each response, mean for each group, the associated Wald statistics and the one-sided p-values are presented in Table 17.

Table 17: *Ordinal regression results for the effect of Major on VOSTS response*

Item		Major	VOSTS response 1	2	3	Mean	Test statistic Wald	*P* <
10111	Defining science	Science	10	65	25	2.15	.400	.527
		Philosophy	15	60	25	2.11	.127	.722
		Humanities	18	58	24	2.06		
70212	Why scientists disagree	Science	20	35	45	2.25	.410	.631
		Philosophy	13	27	60	2.47	.769	.380
		Humanities	24	21	55	2.30		
70721	Scientific method & culture	Science	48	43	8	1.60	3.376	.066
		Philosophy	29	60	11	1.82	.028	.866
		Humanities	30	55	15	1.85		
90111	Influence of theory on observation	Science	45	25	30	1.85	2.107	.147
		Philosophy	38	45	16	1.78	2.723	.099
		Humanities	30	30	39	2.09		
90211	Models as accurate representations	Science	27	58	15	1.88	.297	.586
		Philosophy	7	67	25	2.18	6.939	.008
		Humanities	33	52	15	1.82		
90411	Change in scientific knowledge	Science	18	25	57	2.38	.176	.675
		Philosophy	25	44	44	2.05	2.422	.120
		Humanities	24	21	21	2.30		
90611	Scientific method	Science	35	53	12	1.77	.038	.846
		Philosophy	24	62	15	1.91	1.639	.200
		Humanities	33	61	6	1.73		
90921	Influence of supernatural	Science	60	2	38	1.78	1.718	.190
		Philosophy	55	4	42	1.87	.739	.390
		Humanities	45	3	52	2.06		

Of the eight questions analyzed for differences in VOSTS responses by major, only one question had a significantly different response by major. For this question, models as accurate representations (90211), the philosophy majors' answers had a higher frequency of desired responses than those of the science and humanities students. The mean score for the philosophy majors on this item was 2.18, the mean for humanities majors was 1.82, and the mean for science majors was 1.88. For all other questions, there were no significant differences between VOSTS responses for students with different majors.

Limitations

The results of this study should be interpreted in light of the participants' characteristics and the context of the study. Although efforts were made to ensure that a variety of high school and college-aged participants were involved, it is likely that these participants only represent selected segments of the larger educational system. The expert panel included science educators (preservice teacher educators, science education researchers, and graduate science educators) but did not include experts in philosophy or history of science. The VOSTS items selected do not represent the wider range of items that exist on NOS but instead the selected items represent those that appeared to share NOS characteristics that have been identified by multiple researchers. It is likely that if the entire pool of 114 items were used to assess students' views across the multiple educational levels that other response patterns may emerge.

Discussion

The careful alignment of the selected VOSTS questions with other science education research on the nature of science increases the likelihood that these questions have content validity. The panel that rated the VOSTS responses confirmed this alignment. The evidence for VOSTS validity includes its alignment with student views, its ability to reduce ambiguity when interpreting responses, and the alignment of other selected questions with the research literature.

There were no significant differences in the ways participants at different education levels viewed the definition of science (item 10111). The data showed that half of the participants who did not choose the most acceptable response of viewing science as a way of exploring the unknown instead viewed science as a body of knowledge. Given the way that science is typically taught and the fact that students experience science as a topic of study in both high school and college levels rather than a process of inquiry, these results are not surprising.

As for the change in scientific knowledge (item 90411), high school students outperformed college students. When VOSTS responses are analyzed with education level as a covariate, the results of this item were different from the results of the six remaining questions. One explanation is that a higher proportion of college students took the opportunity to write in their own viewpoint for this question and the conservative scoring approach used underestimated these responses.

Significant differences were found by educational level for the questions that focused on the reliance of empirical evidence, the scientific method and cultural effects, the relationship between models and the reality they represent, and the role of the supernatural in science. High school students were the least likely of all participants to indicate that scientists would disagree for multiple reasons, including different theories, facts, or other cultural influences. They were also least likely to think that scientists think and experiment differently, thereby affecting the types of observations they make. High school students were least likely to consider scientific methodologies as logical approaches to problem solving and were more likely to identify characteristics of a single, step-wise methodology as being representative of "the scientific method." Additionally, they were least likely to consider that scientists in different areas of the world may do their work in different ways.

High school students were also least likely to identify models as representations of reality because they change with time and knowledge. This item, 90211, was also the only item to indicate any difference in response by major, with philosophy students most likely to recognize models as constructs that change. Finally, the high school students were the least likely to recognize that assuming the interference of a supernatural being in natural events might change the way science is done and the way scientists conceptualize nature.

While area of study did not result in higher VOSTS scores, there was evidence that NOS understandings improved during post-secondary education. It is possible that there may be an underlying explanation for differences in VOSTS response between participants (such as one or more aspects of cognitive development) that might provide a more consistent explanation of NOS understanding. The fact that the VOSTS identified some differences between individuals based on educational level suggests that NOS understandings might develop even when explicit NOS instruction may not be provided. Since this study failed to demonstrate a linear relationship between years of education and NOS understanding, more investigations should be conducted to investigate the long-term benefits of explicit NOS instruction.

The outcomes of this study suggest that students may develop NOS understandings through traditional instruction beyond the high school years. More research is needed to better understand the characteristics of post-secondary education that provide students with an opportunity to better understand NOS. If these factors were understood, they could be used to design instruction aimed at promoting scientific literacy. These factors could be manipulated to help in-service and pre-service teachers develop scientific habits of mind, understand the role of technology in society, and appreciate the potential for science to improve the lives of all (Rutherford & Ahlgren, 1990). Furthermore, if NOS can be more readily developed beyond the K-12 years, a re-evaluation of the calls for NOS instruction, most especially in the early years, may be warranted. As studies that relate a cognitive developmental model to NOS understanding are conducted, more evidence will be available to discuss this possibility for curriculum.

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EXPLORING DIFFERENCES IN VIEWS OF NATURE OF SCIENCE AS A FUNCTION OF THE DEVELOPMENT OF REFLECTIVE THINKING

Science education has recently captured the attention of the American public as some states and local school systems grapple with the issue of teaching evolution in public schools (Christoff & Higgins, 2006; Canham; 2006). Since the beginning of 2006, state legislators in Oklahoma, Missouri, Mississippi, Alabama, Utah, and Indiana have introduced bills to undermine evolution instruction (National Center for Science Education, 2006). A significant factor in this debate is the degree to which the public understands the methods scientists use to generate their claims about the origin of species. These methods are distinctly different from the methods used to generate knowledge in other disciplines. It is evidence in the debate about evolution that people approach the problem from multiple points of view or ways of knowing: political, philosophical, religious, or scientific. Each of these ways of knowing draws on specific skills and uses evidence in different ways (Aikenhead, 1979).

As a way of knowing, science values logical approaches to gathering empirical data. Scientists conduct experiments and record observations while assuming the natural world behaves in a consistent manner. They design their instrumentation to provide accurate and precise results that can be replicated in various venues. The strength of scientific claims rests in part in science's commitment to physical evidence and its stated willingness to reform in light of newly acquired evidence (Aikenhead, 1979). Science educators want students to understand these characteristics of science because in a democratic society in which multiple methods of inquiry are valued, it becomes critical that cultures can discriminate between knowledge claims and understand the boundaries and limits of particular ways of knowing.

In order to guide an understanding of the characteristics of science, teachers need to be able to help K-12 students understand science as a unique way of knowing. Furthermore, students need to be able to apply this knowledge when making decisions as citizens. Since very few public school students become scientists, some researchers suggest that the design of science curricula should be focused on those scientific principles most likely to influence public discourse and personal action (Millar, 1996) or based on the ideas that have practical use for most students (Osborne, et al., 2003). While the historic approach suggests that the goal of teaching science is to prepare students for college or careers in science (Klopfer, 1969), a more modern aim for science education is the preparation of more effective citizens (Smith & Scharmann, 1999). One of the ways this aim has been addressed is through the use of Science-Technology-Society (STS) topics in classrooms.

STS approaches to instruction often present real world so that students will use their scientific understanding to develop a solution. These problems might include irradiated or genetically modified foods, nuclear power, stem cells, or cloning. The public discussion of the inclusion of evolution instruction in schools is similar to these problems in that multiple stakeholders, who value different ways of knowing, have come forward to participate in the debate. A significant part of the scientific understanding required to engage more fully with these issues is adequate conceptions of the nature of science (NOS). NOS focuses on making the tentative, empirical, replicable, creative, and social aspects of science explicit during instruction (Lederman, et al., 2002). These characteristics of NOS for K-12 instruction are consistently described in the science education literature and standards documents (Lederman, et al., 2002; McComas & Olson, 1998; Osborne, et al., 2003).

The goals of NOS instruction and STS topics are bound by an implicit relationship (Sadler, et al., 2002). When students deal with the issues associated with STS, they must deal with various viewpoints to problems that have moral consequences. These types of topics can confront students' most deeply held beliefs and challenge them to defend their positions. Additionally, lay people often express frustration in trying to interpret the meaning of debates on STS issues and believe that disagreement among scientists is due to personal interests, personal opinions, or incompetence (Kolso, 2002). When scientists disagree about a topic, as they often do with the ill-structured problems associated with STS, the citizen is often left to include other knowledge, as well as their own interests and values when forming their opinions of the issue (Kolso, 2002).

While individuals are grappling with making a decision on an STS topic, their understandings of NOS are thought to be an important factor. With regard to these complex problems, additional factors are at play. For example, one individual may value the viewpoint of a trusted authority over evidence from competing ways of knowing. Another individual may draw from knowledge claims from multiple disciplines in order to synthesize his/her own conceptions of the situation. Still, a third person might continue to view claims about the world as only having two sides, leaving very little room for integration of concepts from differing domains. Someone else might not choose to use evidence when describing his/her rationale for making a particular decision.

These possible methods for approaching complex problems have been documented as a developmental continuum. At one end of the continuum are individuals who do not often recognize the relationship between evidence and conclusions, who see the world through a very dualistic lens, and are likely to trust particular authorities as having the ultimate final say on a myriad of issues, whether other experts would value that individuals' opinion or not. Individuals at this end of the continuum are considered pre-reflective thinkers (King & Kitchener, 1994).

The center of the continuum harbors individuals who begin to view knowledge as something that resides within the individual. This relativistic viewpoint (e.g. Perry, 1970) is coupled with an emerging willingness to consider evidence and the ability to begin to distinguish consistently between opinion, belief, and evidence. These quasi-reflective thinkers (King & Kitchener, 1994) are moving away from the concrete thinking associated with pre-reflective persons and toward initial stages of abstract thinking.

At the other end of the continuum are individuals who evaluate knowledge claims based on the evidence used to support them and on the methodologies and assumptions used to gather that evidence. While they recognize that individuals have a variety of viewpoints, they are able to reason across perspectives and can draw conclusions about complex problems based on a set of criteria they can support in multiple ways. These reflective thinkers (King & Kitchener, 1994) are more comfortable with ambiguity and are able to describe the reasoning patterns of others with whom they may fundamentally disagree.

For a layperson challenged to make a decision about a complex problem, there are multiple factors to consider. Science educators hope that one such factor in use is a person's understandings of science as a way of knowing. Yet, what if the individual's ability to understand NOS is related to the degree to which they are able to reason in a reflective way? A pre-reflective thinker who values the opinions of a parent who opposes evolution may be unwilling to even acknowledge the evidence supporting evolution presented in science class. Since pre-reflective thinkers do not typically distinguish between evidence and opinion, the methods used to gather that evidence are not thought of as significant reasons to accept the evidence. Thus, it is reasonable to expect that pre-reflective thinkers may be least likely to understand science as a way of knowing.

Similarly, a quasi-reflective thinker challenged to take a position on the use of stem cells may find this task rather difficult. Since these thinkers are most likely to believe that knowledge is idiosyncratic, they are uncomfortable considering that one point of view may be more grounded in evidence than another or that some evidence might be stronger than others. They would likely attribute differences between authorities as being products of those authorities' upbringing.

This study seeks to determine if there is a relationship between the development of reflective thinking and understanding science as a way of knowing. Since reflective thinking occurs in a developmental sequence, if there is a relationship between NOS understandings and reflective thinking, the developmental model can be used to better inform the design of lessons for addressing NOS in science classrooms. Before discussing the methods used to investigate this question, a review of the model describing the development of reflective thinking will be presented, as well as the design of the assessment of NOS understandings.

Reflective Judgment

King and Kitchener (1994) have proposed the Reflective Judgment Model (RJM) to describe how reflective judgment develops within an individual. This field of research focuses on individuals' beliefs regarding the ways knowing occurs, the requirements for something to be knowledge (as compared to constructs like beliefs), where knowledge resides, and the ways this knowledge is constructed and evaluated (Hofer, 2004). The RJM focuses specifically on the development of complex reasoning skills in late adolescents and adults by analyzing the way their assumptions about knowledge are related to their methods for making judgments about controversial, complex, and ill-structured issues (King & Kitchener, 2004).

The RJM is built from the earlier work of William Perry (1970). Perry's repeated interviews with undergraduates revealed their perspectives of knowledge, set forth in a series of nine epistemological positions that described the students' commitments to authorities, their ability to deal with uncertainty and difference of opinion, and their willingness to eventually commit to a particular perspective. The final position in the scheme describes a student's understanding of committing to a perspective as one that continually evolves, and is essentially a relativistic perspective (Perry, 1970). The RJM is unique from this and other models of intellectual judgment in two important ways. First, it focuses specifically on the relationship between personal epistemology and judgment about complex, controversial issues along a developmental sequence (King & Kitchener, 1994). Secondly, the model acknowledges that it is possible to hold epistemological positions that go beyond the relativistic perspectives identified by Perry (King & Kitchener, 1994).

The RJM describes the way individuals use epistemic cognition to solve ill-structured problems. When individuals reason using epistemic cognition, they are thinking using their cognitive and metacognitive skills, in addition to considering the boundaries of what can be known, the certainty of knowledge, and the criteria that need to be met in order for a claim to be called knowledge. Epistemic cognition also includes the methods an individual uses to first identify possible solutions and then choose the most appropriate one based on the nature of the problem. This process of choice requires the individual to understand the nature of the problem and to be able to articulate the limitations to any method they might choose to solve the problem (Kitchener, 1983).

Problems are considered ill-structured when they cannot be well defined, when they may require the application of several algorithms or when the choice of a single algorithm is not clear. Ill-structured problems occur when the proper application of the answers requires a judgment or evaluation on the part of the problem solver (Churchman, 1971). These problems are also characterized as those that have basic assumptions, evidence, or opinions that are in conflict and may lead to multiple, different solutions (Kitchener, 1983). The concepts involved are interdependent and complex; creating messiness the thinker must sort through (Jones & Spiro, 1992). The dilemma for the problem solver is to determine the assumptions, evidence, or opinions that fit the problem best or to find a way to integrate these ideas into a single solution (Kitchener, 1983).

Ill-structured problems require that the individuals considering them think about the reliability, validity, and accuracy of evidence, the opinions of experts, and the types of arguments that are used in resolving the issue. Typically, synthesis of data and opinion must occur in order to arrive at a solution. These types of problems use both metacognitive and epistemic cognitive skills (Kitchener, 1983). Issues typically associated with STS instruction are considered ill-structured problems (Zeidler, et al., 2005).

The Stages of the Reflective Judgment Model. The RJM describes seven stages, or patterns, that have emerged from several longitudinal studies evaluating the reasoning used by individuals as they solve ill-structured problems. The stages appear in a sequential manner, with higher stages reflecting more complex, interrelated, and abstract thinking (Kitchener, et al., 1989). Within each stage, researchers consistently observe patterns in the way individuals view knowledge and the ways they use justification when choosing between competing knowledge claims. Figure 1 summarizes these seven stages of judgment (King & Kitchener, 1994).

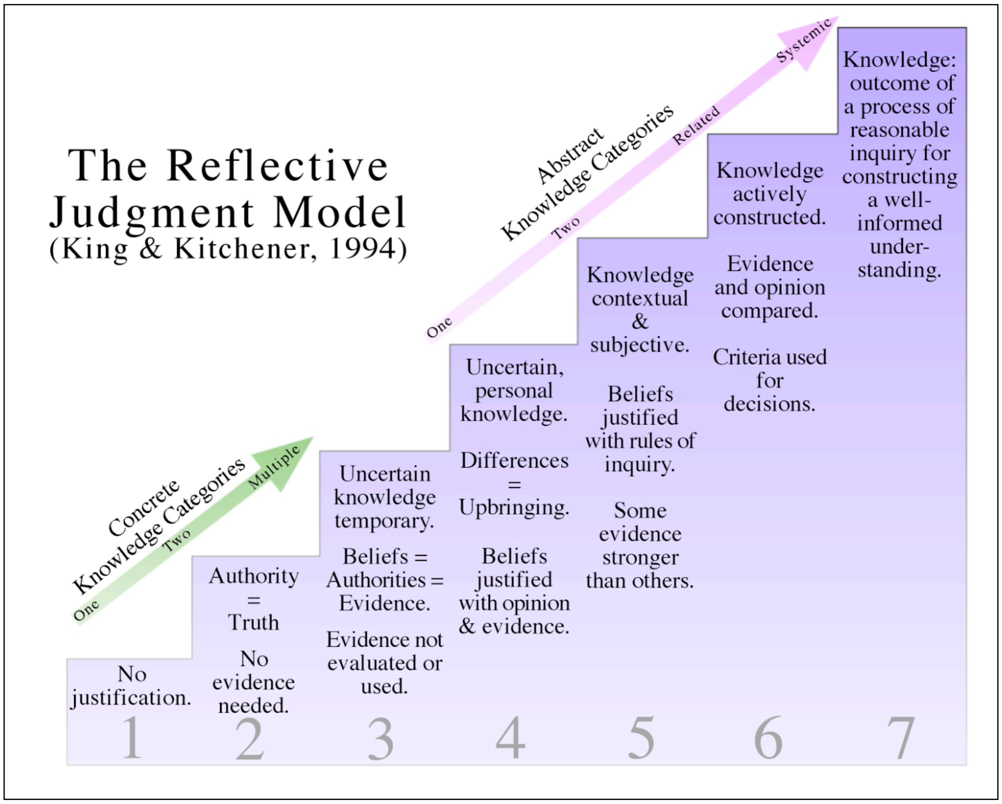

Figure 1: Graphical representation of the Reflective Judgment Model.

After investigating the development of reflective judgment for over 20 years, King & Kitchener (1994) argue that no individual's reasoning lies completely within one single stage at any given time. However, results do suggest that individuals' reasoning patterns occur in sequenced stages (i.e., across stages 1, 2, and 3, but not 2, 4, and 6) (Kitchener, et al, 1989). Typically, high school students begin ninth grade demonstrating early stage three thinking and this progresses upward a quarter of a stage by their senior year. If these students continue on to post-secondary education, they typically reason in stage four by their senior year of college. Master's and early doctoral students typically reason in ways associated with late stage four, with late doctoral students reasoning in stage five (King & Kitchener, 1994).

Reflective judgment is correlated with age, educational levels, and verbal ability. Advanced doctoral students and adults over the age of 65 regardless of past education often exhibit reflective thinking. The model has been used to describe changes in epistemic cognition that occur during the learning process and to evaluate the success of undergraduate education at helping young adults advance along the developmental continuum (King & Kitchener, 1994). Additionally, it has been linked to the development of particular personality traits (Friedman, 2004) and students' behavior as they seek new information in libraries and on the internet (Whitmire, 2004).

Nature of Science

NOS objectives for K-12 instruction are focused on helping students understand scientific knowledge claims are based in empirical evidence, are subject to rigorous testing, and try to explain natural phenomena. The creativity of scientists helps advance the scientific enterprise by building from the previous work already completed. These factors result in a variety of methodologies subject to standards of replicability. As previously noted, one of science's most unique characteristics is its openness to future revision (Aikenhead, 1988; Lederman, et al., 2002; McComas & Olson, 1998; Osborne, et al., 2003). NOS is more than a philosophical concern or construct; it has implications for teaching and learning science (Akerson, et al., 2000; Lederman, 1986).

Multiple studies have documented the difficulties in developing these understandings with K-12 students and their teachers (Bell & Lederman, 2003; Kubasko, 2003; Liu & Lederman, 2002; Moss, et al., 2003). A variety of interventions, including summer internships (Bell, et al., 2003; Liu & Lederman, 2002), specialized school science units (Kubasko, 2003; Moss, et al., 2003), in-service teacher workshops (Klopfer, 1969), and preservice teacher education (Abd-El-Khalick, 2000), have been developed and have yielded mixed results. Expertise in scientific content does not seem to impact the decisions individuals make (Bell & Lederman, 2003), or understanding NOS (Klopfer, 1969; Dotger & Jones, 2006), suggesting that NOS is a separate construct from science content and that other decision making factors might be at play.

Study Description

Instrumentation

Measuring Reflective Judgment. When the RJM was first established, an interview protocol, called the Reflective Judgment Interview (RJI), was used for assessment. More recently, a paper-pencil instrument has been designed to assess individuals' reflective judgment. The Reasoning about Complex Issues Test (RCI) (Wood & Kardash, 2002) presents the respondents with a set of ill-structured problems similar to those used in the RJI. The recognition component of the RCI was used in this study to assess reflective judgment. The recognition component presents five different ill-structured problems to the participants, requiring participants to write a short answer for each problem. Following the short answer, they are asked to compare their answer to ten sample responses representing the seven stages of reflective judgment. During this comparison, the participants rate the degree to which these sample responses agree with their own response on a Likert scale. Once the rating of the sample responses is completed, the respondents choose three statements that they believe most closely correspond to their own views and rank these three statements. In order to control for selections based on perceived sophistication of the answers, statements are included that are grammatically correct but nonsensical. The results are analyzed to identify the level of reasoning used most frequently by the participants across all dilemma topics.

Previous use of this section of the RCI has resulted in a Cronbach's alpha ranging in the low to mid .70's (Wood, et al., 2002).

Measuring NOS understandings. Ten questions were selected from the Views-on-Science-Technology-Society instrument (Ryan & Aikenhead, 1992). Eight of these questions were aligned with the principles of NOS and are described in full detail elsewhere (Dotger & Jones, 2006). Two of these questions were selected due to their focus on the influence of science on decision-making and the influence of culture. All ten of these questions were scored using a rating system established by a five-member panel of science educators. The overall degree of agreement for the body of questions was .869, as determined by a Kendall's W test of concordance (Dotger & Jones, 2006). These two additional questions and their rating systems are included in Appendix A.

Participants

Three hundred and twenty-three individuals participated in this study by completing 10 questions from the VOSTS and the recognition component of the RCI. These participants included high school students, undergraduates, graduate students and post-doctoral fellows who were recruited from multiple institutions using a variety of methods. These groups were selected because in prior research, they demonstrated the range of stages of reflective judgment.

High School Students. Ninety-one high school students were recruited from two schools in a rural, southeastern state. One school is a charter school and the other is public. Ninety-seven percent of the students in the charter school are white and none of them are economically disadvantaged. In the public school, eighty-one percent of the students are white and twenty-one percent of the students in the school are considered economically disadvantaged. Students in both schools performed above the state average on tests of biology and chemistry (www.ncpublicschools.org).

Undergraduate Freshmen. Eighty four undergraduate freshmen volunteered for the study. They all attended a large, public, research institution and were enrolled in a course that required them to participate in one research study of their own selection. These volunteers were given course credit for their time.

Undergraduate Seniors and Graduate Students. Undergraduate seniors, masters' students, and post-doctoral fellows were volunteers recruited by emails sent to their personal accounts describing the purpose of the study and the time commitment involved. These students were enrolled in four different universities, two public, and two private. The student enrollment in the public institutions was 22,754 and 16,525 students, respectively. For the private institutions, the enrollment was 6,301 and 4,272 students (College Foundation of North Carolina, 2005).

Participant Demographics. Fifty-eight percent of the study participants were female. Five percent of the participants identified themselves as Black, 6% as Asian, 2% as Hispanic, 86% as White, and 1% as other. Although all college-educated participants were asked to report their major, this factor was only considered significant for undergraduate seniors and graduate students since undergraduate freshmen change their major at least once during their first year of college study (Registration and Records, 2005). Additionally, even if the student maintained his/her major from the freshman year, the effect of this major on their views after 2 to 4 weeks of classes was expected to be minimal.

Undergraduate seniors, masters' students, and post-doctoral fellows represented 42 different majors. Thirty seven percent of the advanced students majored in the humanities, representing 19 majors that were grouped into business (6%), education and psychology (20%), general studies (2%), and literature & social studies (72%). Twenty-three percent of the advanced collegiate participants were philosophy majors. Forty percent of these collegiate participants majored in the sciences, distributed over 22 majors in the areas of biological science (47%), physical science (29%), earth science (12%), applied science (5%), and natural resources (7%).

Analysis

Scoring the Reasoning About Complex Issues (RCI) Test

The recognition portion of the RCI provides respondents with three tasks for each dilemma. The first task is to write a short response to a prompt that presents an ill-structured problem: i.e., causes of alcoholism, preparation for work in the 21st century, immigration policy, and the use of artificial sweeteners. The second task is to read a list of 10 statements that describe various positions regarding the problem. The individual uses a Likert scale to express the degree to which these stated positions align with his/her own. The final task is for the individual to rank the top three statements that are most like their own views.

These statements are written to align to one of the seven stages of the RJM. If the individual ranks three statements, his/her stage is determined by multiplying the stage representing the response most like his/her view by .5, the stage second most like the view by .3, and the stage third like his/her view by .2. For example, if an individual selected a stage 5 statement as most like his/her view, he/she would be awarded 5(.5) = 2.5 points. If his/her second selection was from stage 3, he/she would be given 3(.3) = .9 points. If the third most similar answer was from stage 6, he/she would be given 6(.2) = 1.2 points. The points would be summed: 2.5 + .9 + 1.2 = 4.6. All final scores are averaged across the dilemmas for a final determination of the degree of epistemic reasoning.

The recognition component of the RCI results in an average stage score over the dilemmas. These stage scores were coded into reflective judgment categories of pre-reflective, quasi-reflective, and reflective thinkers consistent with the design of the model. Individuals scoring from 1 to 3.4 were considered pre-reflective, those scoring between 3.5 and 5.4 were quasi-reflective, and 5.5 to 7 were reflective.

Scoring VOSTS responses

The answers to the VOSTS questions were analyzed individually. The responses were coded on a scale from 0 to 3. Responses given 0 points were considered indecipherable. Responses with 1 point were considered unacceptable. For the purposes of analysis, 0 and 1 responses were collapsed since the frequency of their use was relatively small. Responses given 2 points were considered acceptable answers and responses with 3 points were the desired response. Further detail about the questions and the rating rationale is presented in another article (Dotger & Jones, 2006).

VOSTS response by reflective judgment

A multinomial ordinal regression was conducted to test the null hypothesis that VOSTS response did not shift toward the desired response as reflective thinking improved. Table 1 presents the percentage of each VOSTS response for each level of thinking for each question. The table also presents the mean VOSTS score for each reflective thinking category, the Wald statistic for the test and the associated one-sided p-value.

Table 18: *VOSTS response by reflective judgment category*

Question			VOSTS response				Test statistic	
			1	2	3	Mean	Wald	*P*<
10111	Defining science	Pre-reflective	9	45	45	2.36		
		Quasi-reflective	14	58	27	2.13	1.662	.097
		Reflective	14	64	22	2.08		
20411	Science influenced by culture	Pre-reflective	18	64	18	2.00		
		Quasi-reflective	17	68	15	1.98	2.636	.052
		Reflective	13	64	23	2.10		
40221	Science helps make moral decisions	Pre-reflective	63	18	18	1.55		
		Quasi-reflective	51	24	28	1.80	5.563	.009
		Reflective	31	40	30	1.99		
70212	Why scientists disagree	Pre-reflective	27	45	27	2.00		
		Quasi-reflective	26	33	41	2.15	12.951	.000
		Reflective	14	24	62	2.49		
70721	Scientific method & culture	Pre-reflective	82	18	0	1.18		
		Quasi-reflective	44	47	9	1.65	12.743	.000
		Reflective	27	63	11	1.84		
90111	Influence of theory on observation	Pre-reflective	45	27	27	1.82		
		Quasi-reflective	30	36	34	2.04	3.295	.035
		Reflective	43	34	24	1.81		
90211	Models as accurate representations	Pre-reflective	64	18	18	1.55		
		Quasi-reflective	35	51	14	1.80	9.366	.001
		Reflective	18	66	17	1.99		
90411	Change in scientific knowledge	Pre-reflective	45	18	36	1.91		
		Quasi-reflective	17	29	54	2.36	.614	.216
		Reflective	24	32	45	2.21		
90611	Scientific method	Pre-reflective	44	36	18	1.73		
		Quasi-reflective	37	50	12	1.75	3.557	.029
		Reflective	23	67	11	1.88		
90921	Influence of supernatural	Pre-reflective	81	0	18	1.36		
		Quasi-reflective	59	1	40	1.81	.314	.288
		Reflective	60	2	39	1.79		

The null hypothesis of no significant shift in VOSTS response as reflective thinking developed could be rejected for 6 of the 10 questions. Specifically, there was an increase in the mean VOSTS response for reflective thinkers for questions 40221, 70212, 70721, 90211, and 90611.

The VOSTS question that addressed the definition of science (10111) did not indicate a significant relationship with reflective judgment scores. For this question, most respondents indicated that science should be defined as a body of knowledge, an idea that is reinforced during traditional school science instruction. However, a closer look at the percentages of responses reveals that the reflective thinkers were more likely than the other groups to choose an acceptable VOSTS response (2 points).

The question that addressed the reasons scientific knowledge changes (90411) had the fewest number of answer choices (4). This meant that only one answer choice was given 2 points, whereas with other questions, multiple answer choices resulted in 2 points. The lack of significance for this question is likely due to the fact that more quasi-reflective thinkers responded with the desired response than the reflective thinkers.

The distribution of responses to 90921 may have reflected the way the expert panel coded the question. The panel did not feel there was an acceptable response, thus the responses were coded as either 1 or 3. The three individuals that were given 2 points wrote in their responses and the authors decided these were acceptable. A closer look at the means revealed the pre-reflective thinkers were more likely to accept supernatural explanations for natural phenomena than quasi-reflective or reflective thinkers. The lack of difference between the responses of the quasi-reflective and reflective thinkers was the likely contributing factor to the inability to reject the null hypothesis.

The reflective thinkers were more likely than the pre-reflective and quasi-reflective thinkers to think that science and technology can help people make moral decisions by providing them with background information. Reflective thinkers were also most likely to acknowledge that scientists disagree for multiple reasons, other than lack of facts or a misunderstanding of the facts. Additionally, they acknowledged that scientists in different cultures may conduct their investigations differently due in part to differences in education and technology. The reflective thinkers were also most likely to understand that models are not scientific copies of reality because they are capable of change due to change in scientific knowledge. These individuals were most likely to identify the scientific method as a logical and widely accepted approach to problem solving.

Limitations

While every effort was made to recruit individuals for this study in a random and fair manner, there is no guarantee that the individuals who participated are representative of the larger population. Due to the sensitive nature of the RCI and the topics that are covered, the high school and undergraduate freshmen may have responded differently to the questions given that it is likely they were dealing with the greatest amount of stress during the beginning of an academic year in a new school. Additionally, the findings of the study are only as reliable as the methods used to rank the responses on the VOSTS.

Discussion

This study suggests that as reflective thinking develops, individuals are more likely to hold acceptable views of NOS. There was no strong indication that the study participants have experienced explicit NOS instruction called for in the science education literature (*c.f.* Khifse & Abd-El-Khalick, 2002). It seems plausible that given enough time and opportunity, the development of reflective thinking leads to a broader understanding of NOS. Instead, the relationship between reflective thinking and VOSTS response suggests there may be one or more underlying developmental components to NOS understandings. As reported elsewhere (Dotger & Jones, 2006), educational level has a slight relationship to NOS understanding but it does not correlate as highly as the reflective judgment scores. College major did not correlate significantly with NOS scores suggesting that rather than program of study, some other underlying component of cognitive development may be contributing to better understandings of NOS.

As King and Kitchener (1994) have noted, reflective judgment indicates how an individual uses external authorities, relies upon evidence when making decisions, and provides justification during decision-making. If a student is unable to recognize ambiguity, discriminate among multiple sources of evidence, or adjust when presented with new evidence, then would a student be able to fully understand the unique aspects of science such as its tentativeness or the historic basis of scientific knowledge? Previous studies have failed to measure changes in NOS after students experience scientific inquiry. Is this lack of change due to the fact that students have not yet developed the cognitive skills to fully comprehend NOS? Further research is needed to examine whether all aspects of NOS may depend on the development of reflective thinking.

Within the NOS characteristics, are some aspects more appropriate for younger students than others? While this study suggests that more appropriate NOS conceptions are associated with reflective judgment skills that are often detected among graduate students, it does not yet mean the NOS objectives cannot or should not be addressed in earlier years of education. Further research is needed to describe a pathway for the development of NOS understandings throughout K-12 education. If this pathway cannot be defined with the reflective judgment model, then there may be other, as yet undefined, developmental factors influencing NOS.

The study's findings do suggest that middle and high school teachers, whose students are typically pre-reflective, should focus their instruction on helping their students identify the multiple perspectives involved in ill-structured, socio-scientific issues. When asking students to take positions on these issues, teachers should encourage students to ground their positions in evidence. Finally, teachers and science education researchers should remember that changes in cognitive structures are slow. Expecting rapid changes or development in student's views of NOS may be misplaced.

Encouraging teachers to help their K-12 students understand NOS and use this understanding when making decisions is about more than getting the students to recall the tenets of NOS as described by Lederman, et al. (2003). In fact, Lederman, et al., do not suggest that all students need to be able to do is articulate a list of NOS characteristics in order to become scientifically literate. Rather, these tenets exist simply to specify those aspects of the sociology, history, and philosophy of science that are most appropriate for K-12 education.

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APPENDIX

A

Reasoning about Current Issues Part I: "Suppose You Were Teaching..."

Suppose you were teaching an undergraduate course entitled: "Therapeutic Alternatives in the Treatment of Depression" which enrolls honors students at your institution. At your school, honors courses are also writing intensive.

One of the first topics that you have picked for your class deals with controversies surrounding whether to use medications to alleviate depression. You would like students to write a report on this issue by the end of the semester. To get things started, you first want to have students think about the issues involved. You have them read articles which discuss the advantages and disadvantages associated with medications used in treating depression.

After they have read these articles, and before they begin to draft their papers, you then want to give them an exercise to get them to think about what they believe about the articles they have read. This exercise is called a "minute essay" and consists of having students express the their reasoning about the issue in only a few sentences written on a 3" x 5" note card. Specifically, you ask students to respond to the following controversy:

Essay Topic
Some researchers believe that medications should be used to treat people with depression. They argue that medications are a quick, proven, and cost-effective way to treat clients. Other researchers believe medications are not an appropriate way to treat people with depression. They argue that psychological counseling alone is the best way to overcome depression. These researchers believe that the benefits of medication do not outweigh the physical and psychological disadvantages of "using drugs to solve your problems."

You ask your students to consider the articles they have read, think about the issue for two or three days, and then to write a "minute essay" which expresses their viewpoints.

Purpose of this Survey: Basically, this survey is designed to gather information as to how you would judge such written responses from your class. In the questions that follow, we would like you to compare and contrast aspects of six pairs of essays. Instead of using student names, we have used the letters A-F instead. We are not interested so much in how you judge the factual content of the essays, but in understanding how you perceive the rationale for a particular position. Similarly, we are not asking you to grade these essays in accord with your beliefs about this topic, but rather to judge the quality of the arguments made. The essays which have been chosen below are all adapted from interviews with actual students.

Instructions: We are aware that the short responses we are asking you to read may not always provide you with all of the information you feel you need to make a judgment or give an opinion. Nevertheless, we are asking you to make "best guesses" about these students based on what they provided.

We are also not asking you to assign letter grades to these responses, given that the act of grading is closely related to your own philosophy of how students can best learn. Rather, we are interested in learning when and under what conditions you consider some rationales for some points of view to be better than others in some specific respects.

1For each section, please read the two student essays presented and indicate how you would compare these opinions. Circle the appropriate number corresponding to your judgment. 2If you feel that the two opinions are essentially saying the same things but with different wording, or conveying the same ideas, but with one having a larger vocabulary, mark the middle option for that question.

Comparison I

Student A	Student B
From my perspective, I don't think that it's safe to use drugs to get rid of depression. However, everyone has a right to their own opinion. In fact, some people believe that medications are safe. Yet, there are so many variables (such as life- styles, genetic predispositions and long-term effects) and so many different viewpoints, that I don't think that we will ever know for sure. In the meantime, I am open to new information the researchers discover about the best way to treat depression.	We know that medications are not effective in resolving depression. I have read the articles assigned for this class and come to the conclusion that that's what the real researchers and my teachers know. I know that some people, even scientists, believe that medications should be used, but they are wrong to think that. Some of them are just being paid by pharmaceutical companies, while others have made some mistake while conducting their research. Thus, in accordance with these real scientists, I conclude that psychological counseling is the only effective way to help depressed clients.

1. Which of these students do you think is reasoning more complexly about this issue?

Student A is reasoning more complexly about this issue.	Student A is reasoning a bit more complexly about this issue.	Students A and B are reasoning with about the same degree of complexity.	Student B is reasoning a bit more complexly about this issue.	Student B is reasoning more complexly about this issue
1	2	3	4	5

2. If you ignore possible differences between these students in vocabulary for the moment, which of these students would you guess is going to write a paper with more reasoned and systematic conclusions?

Student A is more likely to write reasoned and systematic conclusions.	Student A is somewhat more likely to write reasoned and systematic conclusions.	Papers from Students A and B are equally likely to be reasoned and systematic.	Student B is somewhat more likely to write reasoned and systematic conclusions.	Student B is more likely to write reasoned and systematic conclusions
1	2	3	4	5

3. Which of these students better understands the central issues which should be considered in making a decision about this issue?

Student A has a better understanding.	Student A has a somewhat better understanding.	Students A and B have about an equal understanding of the central issues.	Student B has a somewhat better understanding.	Student B has a better understanding.
1	2	3	4	5

Comparison II

Student C	Student D
I am on the side that medications are not safe, but we can never know without a doubt. There is evidence on both sides of the issue. On one hand, articles from one research tradition related medications to harmful side effects, but on the other hand another family of research studies indicated that the medications are safe. These research approaches evaluate studies relative to their own perspectives and criteria for what is good research, so what they conclude is only relative to their own perspectives.	My opinion is that using medication is not safe. I have read the articles for this class and am convinced the safety of medication use is one of those things that researchers don't know for sure right now. Someday, after more studies have focused on depression, we will definitely know if the medication is safe. Until then, it is just guess work, so it is my perspective that people can believe what they want to believe and participate in the type of therapy they think is the most effective.

1. Which of these students do you think is reasoning more complexly about this issue?

Student C is reasoning more complexly about this issue.	Student C is reasoning a bit more complexly about this issue.	Students C and D are reasoning with about the same degree of complexity.	Student D is reasoning a bit more complexly about this issue.	Student D is reasoning more complexly about this issue.
1	2	3	4	5

2. If you ignore possible differences between these students in vocabulary for the moment, which of these students would you guess is going to write a paper with more reasoned and systematic conclusions?

Student C is more likely.	Student C is somewhat more likely.	Papers from Students C and D are equally likely.	Student D is somewhat more likely.	Student D is more likely.
1	2	3	4	5

3. Which student better understands what kind of problem is being dealt with here?

Student C has a better understanding.	Student C has a somewhat better understanding.	Students C and D have about an equal understanding.	Student D has a somewhat better understanding.	Student D has a better understanding.
1	2	3	4	5

Comparison III

Student B	Student D
We know that medications are not effective in resolving depression. I have read the articles assigned for this class and come to the conclusion that that's what the real researchers and my teachers know. I know that some people, even scientists, believe that medications should be used, but they are wrong to think that. Some of them are just being paid by pharmaceutical companies, while others have made some mistake while conducting their research. Thus, in accordance with these real scientists, I conclude that psychological counseling is the only effective way to help depressed clients.	My opinion is that using medication is not safe. I have read the articles for this class and am convinced the safety of medication use is one of those things that researchers don't know for sure right now. Someday, after more studies have focused on depression, we will definitely know if the medication is safe. Until then, it is just guess work, so it is my perspective that people can believe what they want to believe and participate in the type of therapy they think is the most effective.

1. Which of these students do you think is reasoning more complexly about this issue?

Student B is reasoning more complexly about this issue.	Student B is reasoning a bit more complexly about this issue.	Students B and D are reasoning with about the same degree of complexity.	Student D is reasoning a bit more complexly about this issue	Student D is reasoning more complexly about this issue
1	2	3	4	5

2. Which student has a better understanding of how scientists make conclusions about this issue?

Student B has a better understanding.	Student B has a somewhat better understanding.	Students B and D understand this about equally well.	Student D has a somewhat better understanding.	Student D has a better understanding.
1	2	3	4	5

3. Which student better understands the central issues which should be considered in making a decision about this issue?

Student B has a better understanding.	Student B has a somewhat better understanding.	Students B and D have about an equal understanding of the central issues.	Student D has a somewhat better understanding.	Student D has a better understanding.
1	2	3	4	5

Comparison IV

Student C	Student E
I am on the side that medications are not safe, but we can never know without a doubt. There is evidence on both sides of the issue. On one hand, articles from one research tradition related medications to harmful side effects, but on the other hand another family of research studies indicated that the medications are safe. These research approaches evaluate studies relative to their own perspectives and criteria for what is good research, so what they conclude is only relative to their own perspectives.	The evidence seems reasonable enough to say that counseling alone is a safer strategy. Because the interpretation of the evidence depends on the researcher's perspective and the evidence may change with time, we can never know for sure. However, we have to evaluate the reasonableness of the evidence and decide which type of researcher has more convincingly addressed the issue. We know this view if reasonable if this evaluation fits in with other knowledge we have of the world.

1. Which of these students do you think is reasoning more complexly about this issue?

Student C is reasoning more complexly about this issue.	Student C is reasoning a bit more complexly about this issue.	Students C and E are reasoning with about the same degree of complexity.	Student E is reasoning a bit more complexly about this issue.	Student E is reasoning more complexly about this issue.
1	2	3	4	5

2. Which student has a better understanding of how scientists make conclusions about this issue?

Student C has a better understanding .	Student C has a somewhat better understanding.	Students C and E understand this about equally well.	Student E has a somewhat better understanding.	Student E has a better understanding.
1	2	3	4	5

3. If you ignore possible differences between these students in vocabulary for the moment, which of these students would you guess is going to write a paper with more reasoned and systematic conclusions?

Student C is more likely.	Student C is somewhat more likely.	Papers from Students C and E are equally likely.	Student E is somewhat more likely.	Student E is more likely.
1	2	3	4	5

Comparison V

Student A	Student C
From my perspective, I don't think that it's safe to use drugs to get rid of depression. However, everyone has a right to their own opinion. In fact, some people believe that medications are safe. Yet, there are so many variables (such as life-styles, genetic predispositions and long-term effects) and so many different viewpoints, that I don't think that we will ever know for sure. In the meantime, I am open to new information the researchers discover about the best way to treat depression.	I am on the side that medications are not safe, but we can never know without a doubt. There is evidence on both sides of the issue. On one hand, articles from one research tradition related medications to harmful side effects, but on the other hand another family of research studies indicated that the medications are safe. These research approaches evaluate studies relative to their own perspectives and criteria for what is good research, so what they conclude is only relative to their own perspectives.

1. Which student has a better understanding of how scientists make conclusions about this issue?

Student A has a better understanding.	Student A has a somewhat better understanding.	Students A and C understand this about equally well.	Student C has a somewhat better understanding.	Student C has a better understanding.
1	2	3	4	5

2. Which student better understands the central issues which should be considered in making a decision about this issue?

Student A has a better understanding.	Student A has a somewhat better understanding.	Students A and C have about an equal understanding of the central issues.	Student C has a somewhat better understanding.	Student C has a better understanding.
1	2	3	4	5

3. Which student better understands what kind of problem is being dealt with here?

Student A has a better understanding.	Student A has a somewhat better understanding.	Students A and C have about an equal understanding.	Student C has a somewhat better understanding.	Student C has a better understanding.
1	2	3	4	5

Comparison VI

Student A	Student F
From my perspective, I don't think that it's safe to use drugs to get rid of depression. However, everyone has a right to their own opinion. In fact, some people believe that medications are safe. Yet, there are so many variables (such as life-styles, genetic predispositions and long-term effects) and so many different viewpoints, that I don't think that we will ever know for sure. In the meantime, I am open to new information the researchers discover about the best way to treat depression.	It is hard to wade through all of the evidence, so I really can't say what I believe about this one. You can't say absolutely that medications are the best therapy because people differ from each other in their life-styles, genetic predispositions, and long-term effects. People see things differently and different kinds of researchers use different rules for evaluating data. In spite of that, it is possible to evaluate some data and arguments as stronger.

1. Which student has a more organized approach to how they think about the issue?

Student A is more organized.	Student A is somewhat more organized.	Students A and F have about the same degree of organization.	Student F is somewhat more organized.	Student F is more organized.
1	2	3	4	5

2. Which student has a better understanding of how scientists make conclusions about this issue?

Student A has a better understanding.	Student A has a somewhat better understanding.	Students A and F understand this about equally well.	Student F has a somewhat better understanding.	Student F has a better understanding.
1	2	3	4	5

3. If you ignore possible differences between these students in vocabulary for the moment, which of these students would you guess is going to write a paper with more reasoned and systematic conclusions?

Student A is more likely.	Student A is somewhat more likely.	Papers from Students A and F are equally likely.	Student F is somewhat more likely.	Student F is more likely.
1	2	3	4	5

4. Which student better understands the central issues which should be considered in making a decision about this issue?

Student A has a better understanding.	Student A has a somewhat better understanding.	Students A and F have about an equal understanding of the central issues.	Student F has a somewhat better understanding.	Student F has a better understanding.
1	2	3	4	5

Comparison VII

Student A	Student D
From my perspective, I don't think that it's safe to use drugs to get rid of depression. However, everyone has a right to their own opinion. In fact, some people believe that medications are safe. Yet, there are so many variables (such as life-styles, genetic predispositions and long-term effects) and so many different viewpoints, that I don't think that we will ever know for sure. In the meantime, I am open to new information the researchers discover about the best way to treat depression.	My opinion is that using medication is not safe. I have read the articles for this class and am convinced the safety of medication use is one of those things that researchers don't know for sure right now. Someday, after more studies have focused on depression, we will definitely know if the medication is safe. Until then, it is just guess work, so it is my perspective that people can believe what they want to believe and participate in the type of therapy they think is the most effective.

1. Which of these students do you think is reasoning more complexly about this issue?

Student A is reasoning more complexly about this issue.	Student A is reasoning a bit more complexly about this issue.	Students A and D are reasoning with about the same degree of complexity.	Student D is reasoning a bit more complexly about this issue.	Student D is reasoning more complexly about this issue.
1	2	3	4	5

2. Which student has a better understanding of how scientists make conclusions about this issue?

Student A has a better understanding.	Student A has a somewhat better understanding.	Students A and D understand this about equally well.	Student D has a somewhat better understanding.	Student D has a better understanding.
1	2	3	4	5

3. Which student better understands the central issues which should be considered in making a decision about this issue?

Student A has a better understanding.	Student A has a somewhat better understanding.	Students A and D have about an equal understanding of the central issues.	Student D has a somewhat better understanding.	Student D has a better understanding.
1	2	3	4	5

Part II: Reasoning About Current Issues

Instructions: Because this questionnaire is aimed at understanding how people like you think about various current issues, it asks not only what you think but why you hold the opinions you do.

The Task: You will be shown five short descriptions of some current issues. These issues are similar because people sometimes disagree about the best answer. For each issue, you will be asked consider four general questions.

Question 1: In Question 1, you will be asked for your personal opinion about the issue. Please indicate it in the space provided.

Question 2: For some issues you will be asked: Why experts disagree. For other issues you will be asked: Why you believe the way you do.

Take a moment to consider your opinion about the question. Write down your response to the question in a few sentences in the space provided. (Do not, for example, write down "I think experts disagree." or "I think that food additives are safe." Instead indicate in a few sentences why experts disagree or why you believe the way you do.) Please give the best answer you have to each question.

Question 3. You will be shown statements taken from interviews with people like yourself. Please Indicate which statements are most similar to your own views by darkening the appropriate square.

Boxes VS, S, D, and VD are used to indicate whether your response is Very Similar, Similar, Dissimilar, or Very Dissimilar to your own thinking. For example, if you read sentence A below and decided that it was similar to your views, you would darken the box labeled S as follows:

A. Researchers who are honest will not disagree about whether a particular artificial sweetener is harmful.

It may be that your views on a topic do not exactly match the ones presented here. Please indicate a few statements for each issue which are at least somewhat similar.

A Check on Reading: Because we have found that some people do not read the statements carefully, we have included some statements that should not make sense to you. When you encounter such statements, mark them as "Meaningless" by darkening the M.

Question 4. You will be asked to indicate your first, second, and third choices for which statements are like how you think. Try to rank the top three statements for each issue, even if the statements do not exactly match your views. If only one or two statements are similar to your views, check the "none of these" box in the appropriate rankings.
Please mark only one statement per ranking.

Artificial Sweeteners

People often have to make decisions that may affect their health such as deciding whether to eat foods or drink beverages that contain artificial sweeteners. There have been conflicting reports about the safety of these additives. For example, some studies have indicated that even in small amounts, artificial sweeteners (such as Nutrasweet) can cause health problems, making foods containing them unsafe to eat. Other studies, however, have indicated that even in large amounts, artificial sweeteners do not cause health problems, and that the foods containing them are safe to eat.

1. Please indicate your personal opinion on this issue: I think that artificial sweeteners:
Are not safe for people to eat   I do not know/cannot decide   Are safe for people to eat

2. How is it possible that researchers in the same field disagree about whether a particular artificial sweetener is harmful? (Please write your answer on the lines provided.)

____

____

3. Many people have heard about disagreements among researchers about this, and they suggest different reasons why that might happen.

How similar is each of the following reasons to your own understanding of why researchers disagree?

VS= Very Similar, S= Similar, D= Dissimilar, VD= Very Dissimilar, M= Meaningless

A. Researchers who are honest will not disagree about whether a particular artificial sweetener is harmful.	S D VD VS M
B. Researchers disagree about this issue because, like everyone else, they are confused about the safety of artificial sweeteners. Therefore it is my perspective that what they conclude is just their opinion.	S D VD VS M
C. Researchers disagree whether enough studies have been done that show artificial sweeteners are safe or that these chemicals are not safe.	S D VD VS M
D. Researchers disagree because of the different ways they were brought up and/or the different schools they attended.	S D VD VS M
E. Researchers disagree because they approach the issue with different opinions already in mind about whether additives are safe. As a result, they conduct studies to support their view.	S D VD VS M
F. Researchers arrive at different conclusions because the evidence itself is complex and they examine it from several perspectives. They arrive at a decision by synthesizing their knowledge, experiences, and expert opinions.	S D VD VS M
G. Researchers might say that one view about the safety of a sweetener was better, but they would also say that this viewpoint is relative to a particular way of understanding this issue.	S D VD VS M
H. Researchers disagree because the premeditated hard evidence is synthesized into available belief systems about different comprehensive factual analyses.	S D VD VS M
I. Researchers disagree because they are really studying different facets of the issue and the best ways to address one facet of the issue are different than the best ways to address other facets.	S D VD VS M
J. Researchers disagree because their evaluation of the evidence leads them to defend different conclusions. Some researchers conclusions are more reasonable, however, and reflect a more comprehensive synthesis of the available information.	S D VD VS M

4. Please rank the statements above (A, B, C., etc.) that are most similar to your thinking. Please check only one statement per line. If no statement beyond one or two is at all like your thinking, check the box labeled “None of These” on the appropriate line(s).

Statement is most like how I think.	A B C D E F G H I J
Statement is second most like how I think.	A B C D E F G H I J None of These
Statement is third most like how I think.	A B C D E F G H I J None of These

Preparing the Work Force for the 21st Century

Educators, civic leaders and members of the business community disagree about how to best prepare the work force of the 21st century. Some claim that colleges should emphasize basic subjects such as math, English, or history. If these courses are well-taught, they argue, students will have the general skills necessary for the future. Others argue that the rapid rate of change in the 21st century requires specific training in skills that are adaptable to many situations, such as critical thinking or problem-solving. They argue that colleges should emphasize such general skills in order to better prepare people for learning after they leave college.

1. Please indicate your personal opinion on this issue: I think that colleges should do more to:

Emphasize basic subjects I do not know/cannot decide Specifically teach critical thinking

2. People give different explanations for their opinions about what colleges should emphasize. What is the basis for your point of view about this question? (Please write your answer on the lines provided.)

____

____

3. Many people disagree about this and give different reasons for their own beliefs. How similar is each of the following reasons to the basis for your own beliefs about what colleges should emphasize.

VS S D VD VS= Very Similar, S=Similar, D=Dissimilar, VD=Very Dissimilar, M= Meaningless

A. There isn't much proof on either side of the issue about what colleges should emphasize so I believe what I want to believe. My point of view just makes sense to me.	S D VD VS M
B. The facts aren't very clear because there is so much information involved in deciding what to emphasize in college. So I just believe what seems right to me based on my own background.	S D VD VS M
C. When I hear people I respect say what they believe about how to best prepare the work force of the 21st century, then I know what to believe.	S D VD VS M
D. My beliefs are based on what I have been taught about how people should be educated by those who really understand what will be needed in the 21st century.	S D VD VS M
E. I look at the ocular opinions and the assumptions I can draw from its collusiveness. Generally, the facts of this issue must be probabilistically migrated from that which is proven to that which is unproven.	S D VD VS M
F. My point of view is based on an evaluation of the evidence and its fit with related arguments and assumptions. As a result of that evaluation, I am confident about the reasonableness of my conclusion.	S D VD VS M
G. I believe what I want to believe because there are no correct answers right now. We won't know the right opinion about what colleges should emphasize until some time in the future.	S D VD VS M
H. The issue of what colleges should emphasize is a very complex one. I try to move beyond quick and easy solutions and draw a conclusion after evaluating and weighing the evidence on both sides.	S D VD VS M
I. After comparing the interpretations on both sides of the issue, my point of view seems more reasonable to me because the evidence is stronger and the assumptions on which this view is based seem more valid.	S D VD VS M
J. There are several valid ways of looking at this issue. People's conclusions are related to their assumptions about the nature of the 21st century as well as their values and their understanding of the evidence. People's assumptions determine how they interpret evidence.	S D VD VS M

4. Please rank the statements above (A, B, C., etc.) that are most similar to your thinking. Please check only one statement per line. If no statement beyond one or two is at all like your thinking, check the box labeled "None of These" on the appropriate line(s).

Statement is most like how I think.	A B C D E F G H I J
Statement is second most like how I think.	A B C D E F G H I J None of These
Statement is third most like how I think.	A B C D E F G H I J None of These

Causes of Alcoholism

Some researchers contend that alcoholism is due, at least in part, to genetic factors. They often refer to a number of family and twin studies to support this contention. Other researchers, however, do not think that alcoholism is in any way inherited. They claim that alcoholism is psychologically determined. They also claim that the reason that several members of the same family often suffer from alcoholism is due to the fact that they share common family experiences, socio-economic status, or employment.

1. Please indicate your personal opinion on this issue: With respect to alcoholism, I think that genetic factors:
Contribute at least partially I do not know/cannot decide Do not contribute

2. People give different explanations for their point of view about this issue. What is the basis for your point of view about this question?
(Please write your answer on the lines provided.)

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3. Many people disagree about this and give different reasons for their own beliefs. How similar is each of the following reasons to the basis of your own beliefs?
VS S D VD VS= Very Similar, S= Similar, D= Dissimilar, VD= Very Dissimilar, M= Meaningless

A. When I hear a scientist say whether alcoholism is genetically determined or not, then I know what to believe.	S D VD VS M
B. My beliefs are based on what I have been taught about alcoholism by people who really know the right information.	S D VD VS M
C. There isn't much proof on either side of the issue about the determinants of alcoholism, so I believe what I want to believe. My point of view just makes sense to me.	S D VD VS M
D. After comparing the interpretations on both sides of the issue, my point of view seems more reasonable to me because the evidence appears stronger and the assumptions on which this view is based seem more valid.	S D VD VS M
E. My point of view is based on my analysis of where the weight of the evidence lies. It is more probable because it best accounts for the evidence and other things I know about related topics, such as other addiction, personality, and genetics.	S D VD VS M
F. I look at the quality and density of the proof-claim of this issue and align my assumptions intrinsically. The facts of this issue must be probabilistically migrated from that what is unproven to proven.	S D VD VS M
G. I believe what I want to believe about whether alcoholism is genetically determined because there's no right answer right now and there may never be one.	S D VD VS M
H. There are several valid ways of looking at this issue. People interpret evidence using different criteria; further, their conclusions are related to their assumptions about how scientists do research and draw conclusions.	S D VD VS M
I. The issue of the causes of alcoholism is a very complex one. I try to move beyond stereotypes and draw a conclusion after evaluating and weighing the evidence on both sides.	S D VD VS M
J. The facts aren't very clear because there are so many variables involved in assessing the origins of alcoholism. So I just believe what seems right to me about the causes.	S D VD VS M

4. Please rank the statements above (A, B, C., etc.) that are most similar to your thinking. Please check only one statement per line. If no statement beyond one or two is at all like your thinking, check the box labeled “None of These” on the appropriate line(s).

Statement is most like how I think.	A B C D E F G H I J
Statement is second most like how I think.	A B C D E F G H I J None of These
Statement is third most like how I think.	A B C D E F G H I J None of These

Immigration Policy

Some economic experts claim that a less restrictive immigration policy adds to the overall economic prosperity of the United States. Admission of new immigrants, they argue, expands the tax base and economic competitiveness of American products and services. Other economic experts suggest that such policies result in a drain on the medical, financial and educational resources of the United States. These experts argue that a less restrictive immigration policy harms the economic well-being of the country.

1. Please indicate your personal opinion on this issue: I think that a less restrictive immigration policy would generally: Harm the economic prosperity of the US
I do not know/cannot decide Add to the economic prosperity of the US

2. How is it possible that different economic experts can disagree or arrive at different conclusions about the effect of immigration policy on economic prosperity? (Please write your answer on the lines provided.)

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3. Many people have heard about disagreements among experts about this, and they suggest different reasons why that might happen. How similar is each of the following reasons to your own understanding of why experts can disagree?

VS S D VD VS= Very Similar, S= Similar, D= Dissimilar, VD= Very Dissimilar, M= Meaningless

A. Experts disagree because they approach the issue with different opinions already in mind and then find evidence to support their own opinion.	S D VD VS M
B. Experts who are honest will not disagree about whether a less restrictive immigration policy improves or reduces the over all prosperity of the United States.	S D VD VS M
C. Experts disagree about this issue because, like everyone else, they are confused about the role that immigration policy plays in economic prosperity. So what they conclude is just their opinion.	S D VD VS M
D. Experts disagree about whether enough research has been done to show that a less restrictive immigration policy contributes to or reduces the prosperity of the United States.	S D VD VS M
E. Experts disagree because of the different ways they were brought up and/or the different schools they attended.	S D VD VS M
F. Experts might say that one view about the contribution of immigrants to economic prosperity was better, but they would also say that this viewpoint was relative to a particular way of understanding this issue.	S D VD VS M
G. Experts disagree because the rule for allusiveness offers a solidified basis for choosing whether immigrants contribute to economic prosperity or reduce it.	S D VD VS M
H. Experts arrive at different conclusions because the evidence itself is complex and they examine it from several perspectives. They arrive at a decision based on synthesizing their knowledge, experience and other expert opinions.	S D VD VS M
I. Experts disagree because they are really interested in different facets of the issue and the ways to more clearly understand one facet of the issue are different than the ways to more clearly understand other facets.	S D VD VS M
J. Experts disagree because their evaluation of the evidence leads them to defend different conclusions. Some experts conclusions are more reasonable, however, and reflect a more comprehensive synthesis of the available information.	S D VD VS M

4. Please rank the statements above (A, B, C., etc.) that are most similar to your thinking. Please check only one statement per line. If no statement beyond one or two is at all like your thinking, check the box labeled “None of These” on the appropriate line(s).

Statement is most like how I think.	A B C D E F G H I J
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Statement is third most like how I think.	A B C D E F G H I J None of These

Determinants of Homosexuality

People often wonder about the causes or origins of a person's sexual orientation. Some researchers suggest that homosexuality is attributable to innate biological traits. Recent research on the model of biological causation has suggested brain structure differences, hormonal influences, or genetic traits that may predetermine an individual's sexual orientation - perhaps even before birth. Other researchers believe that a homosexual orientation occurs after birth in response to social factors, subjective childhood experiences, or personal choice. These people assert that sexual orientation is a learned behavior that is largely a matter of personal preference and can be unlearned or changed.

1. Please indicate your personal opinion on this issue: I think that homosexuality is:
Biologically determined   I do not know/cannot decide   Learned in response to environmental factors

2. People give different explanations for their point of view on the determinants of homosexuality. What is the basis for your point of view about this question? (Please write your answer on the lines provided.)

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3. Many people disagree about this and give different reasons for their own beliefs. How similar is each of the following reasons to the basis of your own beliefs?

VS S D VD VS= Very Similar, S= Similar, D= Dissimilar, VD= Very Dissimilar, M= Meaningless

A. There isn't much proof on either side of the issue about the causes or origins of homosexuality, so I believe what I want to believe. My point of view just makes sense to me.	S D VD VS M
B. After comparing the interpretations on both sides of the issue, my point of view seems more reasonable to me because the evidence appears stronger and the assumptions on which this view is based seem more valid.	S D VD VS M
C. When I hear a scientist say whether sexual orientation is biologically determined or not, then I know what to believe.	S D VD VS M
D. My beliefs are based on what I have been taught about homosexuality by people who really know the right information.	S D VD VS M
E. I look at the optimism of the knowledge on this issue and consider my values absolutely. The evidence of this issue must be evolutionarily summed to determine what is proven.	S D VD VS M
F. My point of view is based on my analysis of where the weight of the evidence lies. It is more probable because it best accounts for the evidence and other things I know about related topics, such as other aspects of sexuality and human behavior.	S D VD VS M
G. I believe what I want to believe about the causes of homosexuality because there's no right answer right now and there may never be one.	S D VD VS M
H. The issue of the causes of homosexuality is a very complex one. I try to draw a conclusion after evaluating and weighing the evidence on both sides.	S D VD VS M
I. The facts aren't very clear because there are so many variables involved in assessing the origins of sexual orientation. So I just believe what seems right to me about the causes.	S D VD VS M
J. There are several valid ways of looking at this issue. People interpret evidence using different criteria; further, their conclusions are related to their assumptions about how scientists do research and draw conclusions.	S D VD VS M

4. Please rank the statements above (A, B, C., etc.) that are most similar to your thinking. Please check only one statement per line. If no statement beyond one or two is at all like your thinking, check the box labeled “None of These” on the appropriate line(s).

Statement is most like how I think.	A B C D E F G H I J
Statement is second most like how I think.	A B C D E F G H I J None of These
Statement is third most like how I think.	A B C D E F G H I J None of These

20411. Some cultures have a particular viewpoint on nature and man. Scientists and scientific research are affected by the religious or ethical views of the culture where the work is done.

Your position, basically: (Please read from A to J, and then choose one.)

Religious or ethical views DO influence scientific research:

A. because some cultures want specific research done for the benefit of that culture. (**2**)

B. because scientists may unconsciously choose research that would support their culture's views. (**2**)

C. because most scientists will not do research which goes against their upbringing or their beliefs. (**1**)

D. because everyone is different in the way they react to their culture. It is these individual differences in scientists that influence the type of research done. (**2**)

E. because powerful groups representing certain religious, political or cultural beliefs will support certain research projects, or will give money to prevent certain research from occurring. (**3**)

Religious or ethical views do NOT influence scientific research:

F. because research continues in spite of clashes between scientists and certain religious or cultural groups (for example, clashes over evolution and creation). (**2**)

G. because scientists will research topics which are of importance to science and scientists, regardless of cultural or ethical views. (**2**)

The panel decided that E was the most acceptable answer because it reflected a mechanism for the influence of religious and ethical views on science. Answers A, B, and D were given 2 points each because they acknowledged the influence of culture on scientific research. Although choices F & G were under the stem focusing on views not influencing research, these choices reflected phenomena the panel felt occurred in some cases. Answer choice C was given 1 point because it described the influence of views as being only based on idiosyncratic differences between scientists.

40221. Science and technology can help people make some moral decisions (that is, one group of people deciding how to act towards another group of people).

Your position, basically: (Please read from A to I, and then choose one.)

Science and technology can help you make some moral decisions:

A. by making you more informed about people and the world around you. This background information can help you cope with the moral aspects of life. (**2**)

B. by providing background information; but moral decisions must be made by individuals. (**3**)

C. because science includes areas like psychology which study the human mind and emotions. (**1**)

Science and technology cannot help you make a moral decision:

D. because science and technology have nothing to do with moral decisions. Science and technology only discover, explain and invent things. What people do with the results is not the scientist's concern. (**1**)

E. because moral decisions are made solely on the basis of an individual's values and beliefs. (**1**)

F. because if moral decisions are based on scientific information, the decisions often lead to racism, by assuming that one group of people is better than another group. (**1**)

The panel agreed that science and technology could help someone make some moral decisions. Answer B was given 3 points because the panel felt that the emphasis on the decision being made by an individual made the choice preferable over option A. Although supporting the idea that science could help in moral decision-making, answer C's suggestion that this was due to the study of mind and emotion trivialized the complexity of the problem to the degree that the choice was unacceptable. Answers D through F were all considered unacceptable because they supported the idea that science did not have a place in moral decision-making.